THE FEASIBILITY OF WASTE-TO-ENERGY IN SASKATCHEWAN BASED ON WASTE COMPOSITION AND QUANTITY

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Abstract

Increasing amounts of municipal solid waste are becoming an issue for urban and rural municipalities. One method for dealing with municipal solid waste is converting it into energy.

In Saskatchewan, no waste-to-energy plants for municipal solid waste currently exist. This thesis explores the technical and economic feasibility of developing waste-to-energy facilities in the province in cities and towns smaller than the two largest centers of Saskatoon and Regina.

A waste composition study was performed at 12 municipal solid waste landfills throughout the province with varying demographic and socioeconomic attributes. This study revealed that municipal solid waste across the province did not vary significantly, regardless of different socioeconomic and demographics factors. The average composition of the municipal solid waste in the selected small cities and towns in Saskatchewan was 7% inert, 45% wet putrescible, 33% dry combustible, and 15% plastic, making it suitable for most types of waste-to-energy.

Several types of waste-to-energy were assessed for communities in Saskatchewan. The feasibility of each type of waste-to-energy was assessed based upon the results of the waste composition study, and the quantity of waste required. Starved air incineration, rotary kiln incineration, and landfill gas utilization were found to be the most viable forms of waste-to-energy currently available. Landfill gas utilization was found to be the most economically feasible, with the least amount of environmental impact.

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Abstract

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1.0 INTRODUCTION

This chapter is intended to acquaint the reader with the rationale and need for this research, followed by the specific objectives the author has set out to achieve. The chapter concludes with the general findings from the research study conducted.

1.1 Subject

In North America, waste is usually buried or burned. Burning waste is no longer a common practice, primarily due to inadequate pollution control measures in the past (Vesilind *et al.*, 2002). Municipal solid waste (MSW) landfills are now the method by which most municipalities dispose of their solid waste. Certain components of the waste stream lend themselves inherently to reuse or recycling under the right economic and geographic circumstances (Curlee *et al.*, 1994). For other fractions of the municipal waste stream (e.g. the wet putrescible organic fraction), beneficial recycling or re-use is infeasible in the North American context because it is more expensive than landfill disposal (FCM, 2004). However, this fraction of the waste stream, subsequent to some processing, may have value as fertilizer (Parker and Roberts, 1985). The biological degradation of organic materials almost always yields energy in some form, and in the right conditions such energy can be harnessed (Kayhanian *et al.*, 1991). Similarly, components of MSW such as paper, cardboard, and plastic have an inherent energy value that can be realized by combustion or other means (Anderson and Tillman, 1977). This thesis discusses the technical aspects and feasibility of various techniques of converting MSW into energy in rural Saskatchewan in the context of a study of waste composition.

Waste composition has a major influence on the economic feasibility of waste-to-energy (Lamborn, 1999). Many studies show waste composition varies from community to community based upon demographic and socio-economic factors (Dayal *et al.*, 1993). In order to determine the feasibility of waste-to-energy in small cities and towns in Saskatchewan, understanding of the composition of the municipal solid waste (MSW) is essential.

1.2 Need

Many authorities and communities are aware of the challenges associated with municipal solid waste and are seeking cost effective and environmentally acceptable solutions (Millrath and Themelis, 2003). Not only is the quantity of waste increasing, but alternative waste management strategies are limited as a result of environmental regulations and political and social realities associated with the location of waste management facilities in “willing host” communities. In order to rationally evaluate alternatives, the first step for municipalities is to conduct a waste composition study. Determining the composition of their waste will provide a firm basis upon which to determine the technical feasibility of future waste diversion projects such as recycling, composting, and waste-to-energy.

No evidence could be found on MSW characterization occurring anywhere in Saskatchewan, other than in the two largest centres of Saskatoon and Regina.

In this research, we hypothesized that studying the variation in waste composition at various landfills throughout the province would reveal how the waste stream varied between Saskatchewan communities as a result of demographic and socio-economic factors. This type of study could be useful to other locations in Canada and the world that are similar to Saskatchewan.

Hundreds of small municipal landfills are located throughout the province of Saskatchewan. In many communities, recycling programs are not economical due to insufficient amounts of waste to compensate for the distance to market. Many of these landfills require continuous expansion to accommodate the growing amount of waste being produced. One option many municipalities are considering for reducing their MSW is waste-to-energy (Vesilind *et al.*, 2002). Several different types of waste-to-energy technologies are available, all differing in their associated costs and environmental effects, and the types and quantities of waste they can use. Using municipal solid waste for energy results in a reduction in the total amount of waste going to the landfill. In some cases this reduction can be very significant, reducing landfilling costs and environmental impact. Waste-to-energy can be very appealing to many municipalities, because it turns a liability into a resource that can generate revenue.

1.3 Objectives

The first objective is to determine the waste composition at various small cities and towns in Saskatchewan. As part of this objective, the observed variations in waste composition will be evaluated with respect to potential correlation with socio-economic and demographic factors.

The second objective is to evaluate, based on the results of the waste stream composition study, under what circumstances waste-to-energy will be technically and economically possible in small cities and towns in Saskatchewan. Several different approaches to waste-to-energy will be considered.

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2.0 BACKGROUND INFORMATION AND LITERATURE REVIEW

2.1 Introduction

This chapter provides background information regarding waste stream composition and waste-to-energy technologies. A detailed literature survey was performed regarding methods for waste composition studies, as well as various studies on how waste composition varies with socio-economic and demographic factors. The advantages and disadvantages of several waste-to-energy approaches were also researched.

2.2 Waste Stream Characterization

2.2.1 Importance of Waste Stream Characterization

Little is known about municipal solid waste composition in Saskatchewan, particularly rural Saskatchewan, since waste characterization has never been performed except in the large centres of Saskatoon and Regina. Waste stream characterization is important for developing solid waste management programs; such as recycling, composting, landfill design, and waste-to-energy facilities. Each type of waste-to-energy utilizes certain components of the waste and thus, waste composition plays a major role in determining which type of waste-to-energy is technically and economically feasible for a given waste stream. According to Khan and Burney (1989), the success of any recovery or recycling effort is directly related to accurate determination of solid waste composition.

Incineration

Incinerated municipal waste leaves a residue approximately equal to the inert content (Wilson, 1977). Knowing the composition of the waste will allow for appropriate design of a system to handle the amount and type of residue produced. The waste composition will also affect the amount of energy that can be obtained. Waste streams high in moisture and non-combustible materials may not be suitable for incineration.

Pyrolysis and Gasification

Pyrolysis and gasification can be done very efficiently for the conversion of cellulose, so therefore paper products and other materials high in cellulose are better suited for this type of waste-to-energy (Mantell, 1975). Pyrolysis could be considered for waste streams that contain higher amounts of paper waste. These processes are also well suited for mixed waste streams that contain high amounts of organics (Kumar, 2000).

Anaerobic digestion

Anaerobic digestion utilizes the biologically decomposable fraction of the waste, so knowing how much organic waste is available in the waste stream is an important consideration for this waste-to-energy alternative.

Landfill Gas Utilization and Bioreactor Landfills

As with anaerobic digestion, the amount of methane available from a sanitary landfill also depends upon the amount of biodegradable material. Municipal solid waste composition also affects the leachate quality, landfill gas composition and quality, and waste degradation rates, which are important to landfill gas utilization, and particularly bioreactor landfills (Reinhart and Townsend, 1998).

2.2.2 Methods of Waste Stream Characterization

Municipal solid waste is a very heterogeneous mixture of materials, which makes characterization quite difficult. Two basic methods exist for characterizing municipal solid waste (Kaldjian, 1990; Embree, 1991; Martin *et al.*, 1995; McCauley-Bell *et al.*, 1997): A) site specific sampling, and B) the materials flow approach.

Site Specific Sampling

Site-specific sampling can be done by one of three methods: 1) single sampling of the waste stream, 2) characterization of numerous samples taken over a period of time to account for seasonal variation, or 3) landfill excavation (Martin *et al.,* 1995). Generation rates of municipal solid waste usually peak in the summer and are lowest during the winter. The composition also changes with the season (Klee, 1993); for example, more organic waste will be present in summer and fall due to an increased inflow of yard waste. Site specific sampling methods are typically suitable for defining local waste streams and may be more accurate than the material flows approach; a disadvantage is that the number of samples taken is limited (Embree, 1991). Therefore, the limited number of samples is assumed to represent the entire population from which they were taken. However, a common misconception about waste composition sampling is that exact values need to be obtained. Knowing the exact composition of one waste collection vehicle has limited value, since each truck has different waste (BC Environment, 1991). However, determining an estimated composition can be quite useful for the reasons mentioned earlier.

One difficulty with sampling is determining the number of samples required for a certain desired accuracy. No consensus exists in the literature for a standard sampling and sorting method of solid waste (Martin *et al.,* 1995; McCauley-Bell *et al.*, 1997). One study by Martin and colleagues (1995) found that a maximum of 25 randomly collected samples of 91 kg (200 lb) will reflect each component category of a mixed load with at least 95% confidence level and 2% error. This protocol was successfully tested in Monongalia County of West Virginia (population of 84,370). Carruth and Klee (1969) found that 20 samples were required to obtain a 90% confidence interval at 2% error.

Any number of categories can be used when sorting. Sfeir *et al.* (1999) suggest selection of the commonly used 91 kg (200 lb) sample size is appropriate when sorting into a small number of categories (less than ten). They further suggest sample sizes should be larger when more categories are used. The American Society of Testing and Materials (ASTM) Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste (D

5231-92) recommends the use of 11 categories, though the number should be determined by the purpose of the study. The ASTM categories are:

- Ferrous
- Aluminum
- Glass
- Other in-organics
- Yard waste
- Food waste
- Other organic
- Newsprint
- Corrugated
- Wood
- Plastic

The ASTM standard also provides a method for determining the number of samples required, which is a calculation based upon a desired level of precision (ASTM, 1998):

$$n = (t \cdot \frac{s}{e \cdot \tilde{x}})^2 \qquad (2.1)$$

where:

n = number of samples

t = student t-statistic corresponding to desired level of confidence

s = estimated standard deviation of governing component (%)

e = desired level of precision (%)

x = estimated mean of governing component (%)

As the desired level of precision is lowered, the number of samples required becomes greater. All components of the waste stream are usually assumed to be normally distributed when sampled, though Klee (1993) states that occasionally this is not the case.

Reinhart *et al.* (1996) refer to three techniques commonly used to sample municipal waste: a grid selection technique, quartering and coning, and selecting waste from the centre of the pile. ASTM recommends quartering. Klee (1992) developed a computer program that can be utilized to determine statistically sound sampling protocols for estimating the quantity and composition of solid waste.

According to Lamborn (1999), fewer categories than suggested by ASTM are required when researching the feasibility of waste-to-energy based on waste composition. In researching the possibility of landfill gas generation at the Narre Warren Regional landfill in Victoria, Australia, Lamborn (1999) used four categories: inert, putrescible, plastics and paper. Paper and plastic were considered slowly to moderately biodegradable and the putrescible content to be “readily biodegradable”. These categorizations are important for the selection of waste-to-energy conversion technologies. The relationship between these categories and the ASTM categories will be further discussed in Chapter 3.

Materials Flow Approach

In the materials flow approach, the number and types of products sold are used to make predictions with regards to the quantity and composition of the resulting waste (Martin *et al.*, 1995). A major consideration used to develop such predictive models in this system is the estimated product life (Embree, 1991). The advantage of this method is that an estimate of the overall solid waste stream composition can be accomplished for very large geographical areas. Some drawbacks include the fact that some material components may be left out or poorly estimated because they are not part of the production sector (such as yard waste) (Embree, 1991). Gay *et al.* (1993) found the materials flow approach (or the economic input/output method as they refer to it) to be comparable to estimates obtained from sorting studies, and could prove to be a useful complement or alternative to conventional sorting. However, their study did not attest that the materials flow approach could replace conventional sorting methods.

2.2.3 The Effects of Demographics and Socio-economic Factors on Waste Stream Characterization

The waste generation rate has increased over time in North America due primarily to income and population growth (Chang *et al.*, 1993). The generation rate may also vary with many demographic factors; for example it is significantly less for farm households (Rhyner, 1976).

Previously Performed Waste Stream Studies

Very few waste composition studies have been done in Saskatchewan, but some have been done in the neighbouring province of Alberta. Table 2-1 below shows the waste composition for several locations in four categories that are important for waste-to-energy.

Table 2-1 - Waste composition by % weight at several locations in Alberta, and in Saskatoon.

	Saskatoon*	Edmonton**	Red Deer**	Stettler (Town)**	Stettler (Rural)**	Prairies**
Inert	7	9	9	9	15	14
wet putrescible	45	37	44	37	37	34
dry combustible	39	45	41	40	33	45
Plastic	9	9	6	11	8	6
Other#	0	0	0	3	7	1

* from City of Saskatoon (1998)

** from GCG Dillon Consulting Limited (1992)

inorganic materials that were not assigned a category during the study such as textiles and wood.

Table 2-2 shows a summary of waste stream composition data in Alberta, and compares rural to urban.

Table 2-2 - Summary of Alberta waste stream composition data.*

		Population 5,000		*Small Urban (Pop 300)*		*Rural*
Broad Category	Material	Residential (%)	Commercial (%)	Residential (%)	Commercial (%)	Rural (%)
Wet Putrescible	Food Waste	22.6	28.9	32.3	33.4	27.7
	Yard Waste	16.9	1.6	3.5	1.0	0
	Textile/Leather/Rubber	2.1	1.3	3.1	5.9	1.9
	total:	**41.6**	**31.8**	**38.9**	**40.3**	**29.6**
Dry Combustible	Newsprint	6.8	5.5	10.7	2.7	8.1
	Cardboard	3.3	18.6	1.2	22.3	3.7
	Mixed paper	21.5	21.9	23.7	19.5	19.1
	Wood	0.7	1.1	0.1	1.0	1.2
	total:	**32.3**	**47.1**	**35.7**	**45.5**	**32.1**
Plastic	Plastic	11.4	9.8	9.8	6.8	8.7
	total:	**11.4**	**9.8**	**9.8**	**6.8**	**8.7**
Inert	Metal	4.5	4.5	6.1	2.3	6.6
	Glass	2.9	1.8	3.0	0.9	9.3
	Ceramic/Ashes/Fines	2.1	2.0	4.0	0.3	2.2
	total:	**9.5**	**8.3**	**13.1**	**3.5**	**18.1**
Other	Other:	5.2	3.0	2.5	3.9	11.5
	total:	**5.2**	**3.0**	**2.5**	**3.9**	**11.5**
	TOTAL:	**100**	**100**	**100**	**100**	**100**

*SERM, 1999

Models That Predict Waste Stream Composition Based on Demographic Factors

Composition of municipal solid waste varies from one community to another, as well as with time within any one community (Weiner and Matthews, 2003). According to Grossman *et al.* (1974), four basic factors affect the solid waste generated by a community or household:

- population

- dwelling unit size and character
- income level
- cultural characteristics

Khan and Burney (1989) used multi-linear regression techniques to determine the relation between categories of paper, plastic, food, and certain demographic factors (persons per dwelling, income, climate, population and GDP). The first three of these demographic factors were found to be the most influential. The model uses waste stream composition data (% weight) from various major centres from around the world. More paper in the waste stream was found to be related to higher income. Higher occupancy rates resulted in higher percentages of food; lower occupancy rates resulted in higher percentages of glass. The percentage of metal increased with increasing average temperature. Richardson and Havelick (1978) used a very similar technique for selected United States cities, and developed an equation to determine the quantity of components of waste based on income, household size, percentage of people 18 to 61, percentage of black people, and a random disturbance variable. Their results indicate higher income families produce more newspaper and less clothing, and that household size, household age and income were important factors affecting the waste composition and quantity, but no consistently strong statistical relationship was evident.

Daskalopoulos *et al.* (1998) developed a prediction methodology for waste composition and quantity using data from Europe and the United States. They converted GDP (gross domestic product) data to TCE (total consumer expenditure), which vary linearly with one another. Only a fraction of the TCE is responsible for municipal waste, referred to as the RTCE (related total consumer expenditure). They plotted MSW generation rate versus population and performed a linear regression. The same type of analysis was done for GDP. They showed the two equations could be combined to predict MSW generation based on population and GDP, with waste quantity increasing with GDP. This relationship holds true for Saskatchewan; over the past 20 years, province-wide GDP has been increasing (Saskatchewan Bureau of Statistics, 2005) as has waste production, though exact quantities are unknown (Saskatchewan Waste Reduction Council, 2005). Daskalopoulos *et al.* (1998) also found that the plastic and paper fractions increased with increasing RTCE, while glass, metal and organic fractions tended to decrease. However, none of the relationships between the waste fractions and RTCE were linear.

Hocket *et al.* (1995) researched the determinants of per capita municipal solid waste generation in the south-eastern United States. They studied the effects of per capita retail sales, per capita value added by manufacturing, per capita construction costs, cost per tonne to dispose of waste, per capita income, and urban population percentage on the amount of waste generated, and found retail sales and the waste disposal fee were the most influential.

2.3 Waste-to-Energy Schemes

After determining the composition of the waste, the appropriate waste-to-energy system, if any, can be selected. Several techniques for converting waste-into-energy will be discussed in this section. The principal components involved in recovering the energy from the heat, steam, gases, oils or other products produced in the waste-to-energy process are similar and typically include: boilers for the production of steam, steam and gas turbines for motive power, and electric generators for the conversion of motive power into electricity (Tchobanoglous *et al.*, 1977). This section provides an overview of the waste conversion processes that may be used to yield valuable products such as heat, steam, gases, and oils from the waste. A discussion of some advantages and disadvantages is provided for each of the most common types of waste-to-energy.

2.3.1 Incineration

Process:

Incineration, also referred to as combustion, is a specialized process that involves the burning of organic (putrescible, combustible and plastic) materials in any state to form gases and residue (Vesilind and Rimer, 1981). The basic elements of an incinerator include a feed system, combustion chamber, exhaust gas system and a residue disposal system; whereas modern incinerators use continuous feed systems and moving grates within a primary combustion chamber lined with heat resistant materials (Vesilind and Rimer, 1981). The waste must be mixed, dried, and then heated, all for specific amounts of time and at controlled temperatures (Mantell, 1975). Four different types of incinerators are in common use: mass-fired combustors, refuse derived fuel combustors, modular combustion units, and on-site commercial and industrial incinerators (Salvato *et al.*, 2003).

Four types of incineration have been put to use in Canada: rotary kiln incineration, mass burn incineration, starved air incineration and fluidized bed systems (FCM, 2004). The first three of these are types of mass-fired combustors. Fluidized bed systems do not fall into any of the categories mentioned by Salvato *et al.* (2003). The differences between these four types of incineration will be discussed further in Chapter 3.

Advantages:

The primary objective of incineration is to combust solid waste, reducing its volume and producing non-offensive gases and non-combustive ash residues (Wilson, 1977; Vesilind and Rimer, 1981). Volume can be reduced by 80-95% and weight by 70-80% and thus incineration significantly reduces the land required for disposal of municipal wastes (Baum and Parker, 1974; Vesilind and Rimer, 1981; Salvato *et al.*, 2003;). Although incineration produces air pollutants primarily in the forms of nitrogen oxides, sulphur dioxide, and hydrogen chloride, these emissions can be reduced substantially through combustion modifications and air pollution control equipment (California Air Resources Board, 1984).

Theoretically, incineration could be combined with anaerobic digestion, wherein the residue from anaerobic digestion is incinerated (Pfeffer and Liebman, 1976). By using the steam from incineration as well as the methane from anaerobic digestion, the efficiency of the combined system might be increased to 63%

compared to 32.6% from anaerobic digestion alone. Efficiency, in this case, is defined as the amount of energy produced as a fraction of the theoretical yield based on the total calorific value of the waste. The capital costs of a system that combines anaerobic digestion and incineration would be significantly higher than each of the systems on their own, but the payback time would be much less. Notably, this study performed by Pfeffer and Liebman (1976) was a mathematical simulation rather than an actual full scale demonstration.

Disadvantages:

Incineration has high capital and operating costs (Baum and Parker, 1974; Vesilind and Rimer 1981; Kumar, 2000). A major consideration is operating problems which can occur as a result of variability of the waste over time (Vesilind and Rimer, 1981). Public perception can also be a problem because of air pollution caused by incinerators; this pollution cannot be completely avoided even with the most sophisticated of plants (Vesilind and Rimer, 1981; Kumar, 2000). The most difficult factors to be accommodated in the combustion process are the amounts of moisture and non-combustible materials in the refuse (Mantell, 1975). In general, incineration is not recommended for small towns or villages (size is not specified) unless good design can be assured, and cost is not a factor (Salvato *et al.*, 2003). This is due to the high capital and operating costs, and the requirement for expensive, dedicated and sophisticated operators. A large system is required to compensate for these needs.

2.3.2 Pyrolysis

Process:

Pyrolysis is chemical decomposition by heat in the absence of oxygen converting carbonaceous material into fuel gas that can be used as a substitute for natural gas (Jackson, 1974; Levy, 1974; Advanced Energy Strategies Inc., 2004). The pyrolysis process, like incineration, can be continuous or batch fed (Robinson, 1986), producing char, pyrolysis oils, and gases (Tchobanoglous *et al.*, 1977; Parker, 2000). The process is conducted at 815ºC, most commonly in what is called a fluidized bed (Jackson, 1974; Advanced Energy Strategies Inc., 2004). Cellulose molecules within the municipal waste dissociate instead of burning, due to the absence of oxygen. The fragments of the dissociated molecule form methane, carbon dioxide, hydrogen, carbon monoxide, and water (Jackson, 1974).

Advantages:

The process is highly exothermic (gives off heat) and therefore requires very little energy (Tchobanoglous *et al.*, 1977). It transforms refuse into gaseous or liquid fuel products that can be utilized by a wide variety of end users, including conventional engines and boilers (Tchobanoglous *et al.*, 1977). The gases produced from pyrolysis can be used to create steam, which could become much more valuable with oil price increases in the future (Levy, 1974). The energy recovery rate is considerably higher than that of a conventional incinerator (Jones and Radding, 1980).

Disadvantages:

None of the products of pyrolysis have great value (Parker, 2000) and capital costs and operating costs are high (Jackson, 1974; Parker and Roberts, 1985). The conversion of fossil fuels into fuel gas also requires a large number of skilled personnel (Jackson, 1974). The use of municipal waste as feedstock has had only limited success (Robinson, 1986); pyrolysis has been successfully used for the production of energy from coke, charcoal and other homogenous materials, but no successful field tests in full scale with MSW have taken place (Vesilind *et al.,* 2002). As of 1993 only one full-scale pyrolysis system was built in the Unites States, and it did not achieve its primary operational goals (Tchobanoglous *et al.*, 1993). Failure seems to be due to the complexity of the system and the difficulty of producing consistent feedstock from a heterogeneous municipal solid waste stream (Tchobanoglous *et al.*, 1993; Vesilind *et al.*, 2002).

2.3.3 Gasification

Process:

Gasification is the reaction of organics (combustible, putrescible, and plastic fractions of the waste) with steam, producing carbon monoxide and hydrogen (Parker, 2000). Gasification is a modification of pyrolysis in that a limited quantity of oxygen is introduced, and the resulting oxidation produces enough heat to make the process self sustaining (Vesilind *et al.*, 2002). Gasification occurs at very high temperatures (greater than 700ºC) (Parker and Roberts,

1985) and involves the partial combustion of a carbonaceous fuel, which produces combustible fuel gas rich in carbon monoxide, hydrogen and some saturated hydrocarbons (mostly methane). The combustible fuel the process produces can be combusted in an internal combustion engine (Tchobanoglous *et al.*, 1993). Of the several different types of gasifiers, the mostly commonly used are horizontal or vertical fixed bed, and fluidized beds. (Tchobanoglous *et al*, 1993).

Advantages:

The products of gasification are very useful for making products including methanol, ammonia, and diesel fuel (Parker, 2000). The process is quite energy efficient (60% to 90%; Eden, 1999). Waste volume is reduced by about 90% (Tchobanoglous *et al.*, 1993; Kumar, 2000) and only 8-12% ash is produced compared to 15-20% for incineration (Kumar, 2000). Furthermore, the hazardous by-products produced during incineration such as dioxins and furans are given little opportunity for formation during gasification (Eden, 1999).

Disadvantages:

As of 1993, reliable results with full-scale and pilot-scale gasifiers had not been achieved. At that time, Tchobanoglous *et al.* (1993) stated that gasification systems could not be considered a commercial technology. However, since 1993, some plants have successfully operated on a pilot scale in Canada and the US (Kumar, 2000). According to Advanced Energy Strategies Inc. (2004), application of gasification to municipal waste is still a relatively new development. Removing inert material before using municipal waste in a gasifier is important in order to reduce air pollution and improve performance, but this can be difficult. Particle size distribution, which can be difficult to control, is important to ensure the flow through the gasifier is uniform and blockage does not occur (Eden, 1999). If the moisture content is adequate (between 10% and 20%), air can be used rather than steam. However, most municipal solid waste normally has a moisture content of 50% and some drying may be necessary (Eden, 1999). The product gas may contain particulate matter, heavy metals and other toxic chemicals (Eden, 1999).

2.3.4 Anaerobic Digestion

Process:

Anaerobic digestion is the decay of organic matter (without oxygen) producing primarily carbon dioxide and methane, but also small amounts of hydrogen sulphide, ammonia, and other compounds (Vesilind and Rimer, 1981). The putrescible and combustible (paper) fraction of the waste is removed and placed in a contained digester to decay. Three main steps are involved in anaerobic digestion (Tchobanoglous *et al.*, 1977). The first involves the preparation of the organic fraction of the waste including sorting, separating and size reduction. The second step involves adding moisture and nutrients, blending, adjusting the pH to about 6.7 and heating the slurry to about 55-60ºC. The contents are well mixed for 5-10 days. For colder climates, the slurry is heater to a lower temperature, but mixed for a longer period of time. The third step involves capture, separation (if necessary) and storage of the gas components. The residual sludge must be disposed of (though if free of contaminants, composting may be possible), and treatment of this residual could be considered another step in the process (Robinson, 1986). The micro-organisms responsible for anaerobic digestion can be divided into two main categories: acid formers and methane formers (Vesilind and Rimer, 1981). The acid formers degrade the complex organic compounds to simple acids, then the methane formers convert the acids into methane (Vesilind and Rimer, 1981). Methane forming bacteria are sensitive to many environmental factors; maintaining the appropriate temperature is important, as is preventing oxygen and other substances toxic to the microbes from entering the system (Vesilind and Rimer, 1981). Methane can be generated in two ways: the gases can be captured directly off of the landfill (sanitary landfill or bioreactor landfill) or the refuse can be pre-treated and digested in a tank. Either high solids digesters or low solids digesters can be used. Low solids digesters are a well-developed technology, but considerable amounts of water must be added to the waste. High solids digesters require little addition of moisture, but their technology is less developed (Tchobanoglous *et al.*, 1993). A minimum of 5 ha is required for a 900 tonne/day anaerobic digestion plant (Vesilind and Rimer, 1981); however, this size of plant is much larger than what would be required anywhere in Saskatchewan. Anaerobic digestion of MSW has never been successful in North America on a prototype scale, though it has been successful in Europe where the high cost of landfill space makes it more economical (FCM, 2004; Vesilind *et al.*, 2002).

Advantages:

The purpose of anaerobic digesters is to utilize the gas produced by decomposing refuse as a source of fuel (Vesilind and Rimer, 1981). According to Ricci (1974), anaerobic digestion appeared to be the most popular mechanism for methane production from wastes. Waste can be aerobically composted after anaerobic digestion to obtain the benefits of both biogas as well as humus for soil improvement and fuel for power plants (Kayhanian *et al.*, 1991). De Baere (1984) discusses the use of high-rate anaerobic composting with biogas recovery, which could be an attractive option economically. This process is similar to anaerobic digestion, but the pathogenic materials are removed, allowing for the residual of the digestion to be useable compost. Glauser *et al.* (1987) found anaerobic digestion to be possible even with the natural moisture content of the organic municipal solid waste fraction of about 60%. From the point of view of life cycle cost, anaerobic digestion is comparatively more cost effective (Kumar, 2000).

Disadvantages:

Ensuring the removal of toxic substances before the waste goes into the digester is difficult, and the problem of what to do with the residue from anaerobic digestion has not been solved (Vesilind and Rimer, 1981). According to Parker and Roberts (1985), anaerobic digestion would likely only be feasible if it was combined with sewage or agricultural waste digestion. Anaerobic digestion is commonly used for treatment of sewage and manure because this material is uniform and easily degradable. The addition of such materials to MSW would enhance the digestion process. The current trend for anaerobic digestion seems to be towards larger projects (De Baere, 2000). Anaerobic digestion still has to compete vigorously with aerobic composting (Lissens, 2001).

2.3.5 Landfill Gas Utilization

From a Sanitary Landfill

Process:

Generation of methane from a sanitary landfill is similar to anaerobic digestion, but without operational control of the process. The waste is simply left as is with no efforts made to increase gas production; gas is simply captured as it is generated (Vesilind and Rimer, 1981). Landfill gas typically consists of 50-60% methane, 40-50% carbon dioxide, and trace levels of other gases (Almes & Assoc. and Holditch & Assoc., 1999). Typical landfill gas has an energy equivalent to about half that of natural gas (Almes & Assoc. and Holditch & Assoc., 1999; Oleary and Walsh., 1991). The methane concentration of the gas needs to be about 35% for energy recovery to be worthwhile (Oleary and Walsh, 1991). The decomposition process within a landfill consists of an aerobic stage, anaerobic non-methanogenic stage, anaerobic methane production build-up stage and finally an anaerobic steady state stage (Constega-Rovers & Assoc., 1987). A landfill gas recovery and utilization system includes four basic components: a gas recovery system, a gas pumping system, a gas transmission system, and a gas utilization system (Constega-Rovers & Assoc., 1987).

Advantages:

Methane collected off of the landfill can be used for energy, and as with anaerobic digestion, the amount released to the atmosphere is reduced. Landfills are the largest anthropogenic source of methane, accounting for 40% of these emissions (Almes & Assoc. and Holditch & Assoc., 1999). In the United States, existing landfill power stations (as of 1992) provided energy equivalent to approximately 2.9 million barrels of oil per year, or 570,000 tonnes of coal per year (Valenti, 1992). Gas collection also reduces odours, vegetation damage, and fires, and can be a source of revenue (Environment Canada, 1995). Landfill gas utilization typically requires less maintenance and operation costs compared to anaerobic digestion (Tchobanogolous *et al.*, 1993). Gas extraction is environmentally beneficial, and considerable economic potential exists for methane recovery (Parker and Roberts, 1985). Landfill gas collection is one of the more popular forms of waste-to-energy, and the number of landfill gas to energy projects have increased dramatically in recent years, with a 10% growth per year since 1990 (Thorneloe *et al.*, 1999). In the United States, landfill gas-to-energy projects have climbed from 110 in 1992, to 33 facilities in 1996, to over 140 facilities in 2005 (Thorneloe *et al.*, 1994; World Resource Institute, 2005). In Canada, numbers climbed from 9 in 1992 to 17 as of 2005 (Environment Canada, 2005a; Thorneloe *et al.*, 1994). Landfill gas utilization can be quite simple if a factory or large building is located near the landfill where the gas can be piped directly into a boiler (Oleary and Walsh, 1991). Landfill gas collection is most economical if sufficient land is available and proper care is taken to treat the leachate collected (Kumar, 2000).

Disadvantages:

Although landfill gas is a useful fuel and direct use should increase in the future, estimates from the United States indicate it will unlikely ever contribute more than 0.5% of national gas use (Vesilind and Rimer, 1981). A landfill must have a nearby consumer in order for wells to be economical (Ricci, 1974). Kumar (2000) emphasizes that typically 60% of the total plant cost is in the engines or turbines, meaning that either a consumer must be nearby, or utilities must purchase power from the landfill gas facility at a higher cost.

From a Bioreactor Landfill

Process:

A bioreactor landfill is similar to a regular landfill from which gas is collected, except the waste is stabilized and degraded faster by adding liquid and/or air to enhance microbial processes (EPA, 2004). Three ways of creating a bioreactor landfill include aerobic (with oxygen), anaerobic (without oxygen), and hybrid (partly with and partly without oxygen) (EPA, 2004). All methods utilize leachate recirculation to add moisture and aid with bacterial decay. Anaerobic landfills result in earlier and more rapid methanogenosis (production of methane gas) and are therefore more common (EPA, 2004).

Advantages:

Bioreactor landfills provide decomposition and biological stabilization in years rather than decades or centuries, which is the case for “dry tomb” landfills, (those in which measures are not taken to enhance the rate of decay) (EPA, 2004; Pacey, 1999). Bioreactor landfills also lead to less toxicity in the waste, reduced leachate disposal costs, a gain in landfill space of 15-30%, increased landfill gas generation (but much less released into the environment), and reduced post closure care (Reinhart and Townsend, 1998; Pacey, 1999; EPA, 2004;). Bioreactor landfills are more likely to allow for the actual methane potential of the MSW to be realized, as compared to regular landfills (EPA, 2004). The methane potential of MSW ranges from 100-170 m^3 of methane per tonne of MSW (Thompson and Tanapat, 2004).

Disadvantages:

Compared to the average sanitary landfill, bioreactor landfills produce more gas emissions and odours, have more physical instability of the waste, have increased liner instability, and have increased occurrences of surface seeps and landfill fires (EPA, 2004). In drier climates, such as the Canadian prairies, leachate re-circulation alone may not provide sufficient moisture balance to achieve the optimum moisture content, and moisture must be added from another source (Perera and Van Everdingen, 2005).

2.3.6 Other Types

The following types of waste to energy are not as common as those already mentioned. However, they are briefly discussed here since they may become more popular in the future.

Pelletization

Pelletization is the process of producing fuel pellets from solid waste (Kumar, 2000), and involves drying, removal of non-combustibles, grinding and mixing. Pellets have a calorific value roughly four times the amount of raw garbage (Kumar, 2000).

Thermo Chemical Reduction

This technology is more often applied to hazardous waste, though it has been used in Canada for municipal solid waste. The process is based on the gas-phase thermo-chemical reaction of hydrogen with non organic and chlorinated organic compounds at elevated temperatures (around 1000ºC or more) (FCM, 2004).

Plasma arc (Pyro-plasma process)

This system uses a heat source called a plasma arc flame, which results in the utilization of all organic matter, including the non-biodegradable fraction (Kumar, 2000). This process is still in the developmental stage, and no commercial scale units managing municipal solid waste in North America are in existence.

However, different patented plasma arc systems are proposed for the treatment of hazardous waste (FCM, 2004).

Garret Flash Pyrolysis

This is low temperature pyrolysis (350 to 450ºC) that produces fuel oil (Kumar, 2000).

Fermentation

Fermentation is a biological conversion process used for the production of ethanol. The most suitable feedstocks are wood, agricultural residues, grasses, and the organic portion of municipal waste (Bjeldanes and Beard, 1996).

Refuse Derived Fuel (RDF)

RDF systems treat waste to produce fuel that can be used to substitute conventional fossil fuels, typically coal, in industrial manufacturing, utility power generation, and institutional applications (e.g., district heating). In Canada, one such facility is in operation in Caledon, Ontario, however commercial use of their gas has yet to occur (FCM, 2004).

Fluidized Bed Combustion

Fluidized bed combustors have been commercially used for homogenous wastes, though they can be used for municipal waste as well. The process is similar in some ways to pyrolysis and gasification. Air is injected and dispersed into a sand bed, decreasing the density of the sand mass to enable it to transport air and heat to the particles of waste substance to be treated (combusted). The temperature is raised to approximately 850ºC and the waste is moved into the body of the sand bed by the convection current movement of the air and sand particles. The waste is burned to produce carbon monoxide and other volatiles that can be utilized. The bi-products are flue gases and ash (FCM, 2004).

2.4 Summary

This chapter has outlined the many possibilities for utilization of municipal waste for energy. In order to determine which, if any, are suitable for development in small cities and towns in Saskatchewan, the waste composition and quantity must first be determined. Waste composition analysis was performed in small cities and towns in Saskatchewan for this reason. The methodology and the results of the study are presented in the following chapter. Not all types of waste-to-energy discussed in Chapter 2 have been put to use in Canada. The costs associated with the ones found to be technically feasible in Canada, and their environmental impacts, will be considered in Chapter 4, with respect to waste composition and quantity in small cities and towns in Saskatchewan. Furthermore, many studies have shown demographics can be a major factor in determining the characteristics of the waste stream. The data obtained from the waste characterization study will be analyzed with respect to demographics of small cities and towns in Saskatchewan, and the results discussed in Chapter 4.

3.0 METHODOLOGY

3.1 Introduction

No evidence could be found that sampling of municipal waste in small cities and towns in Saskatchewan has been performed. As discussed in Chapter 2, waste composition is an important factor in determining which types of waste-to-energy are possible (e.g. Khan and Burney, 1989; Reinhart and Townsend, 1998). Some sampling of municipal solid waste has been performed in the two largest Saskatchewan cities of Saskatoon and Regina. Many studies indicate that demographics often have a major impact on the waste stream composition, as indicated in Chapter 2 (e.g., Richardson and Havelick, 1978; Weiner and Matthews, 2003). Therefore, sampling the waste stream in a variety of locations and demographical areas is important to determine whether or not demographics have a major impact on municipal solid waste composition in small cities and towns.

3.2 Selection of Communities for Sampling

Waste composition changes from place to place based upon demographic factors such as population, income and age. Other factors that may influence the composition of the waste are (Green Solutions, 2003):

- The presence of recycling and composting programs
- Climate
- The types of businesses and industries in the area
- The amount of construction activity

- The total amount of green space contributing to yard waste

A waste composition study was preformed at selected small cities and towns in Saskatchewan (defined as communities other than Saskatoon and Regina). In Saskatchewan, a community the size of 5000 people can apply to have the status of a city. Waste-to-energy projects will not be feasible without a sufficient population in the area producing waste. Locations were selected so that each community size was appropriately represented. With one exception, communities greater than 1000 people were selected because a waste-to-energy facility would likely not be feasible in smaller communities. The communities were also selected to represent the various geographical areas of the province and various industries. The communities that were sampled at are indicated with circles.

Table 3-1 shows the communities selected for the waste composition study, and their population based on the 2001 census performed by the government of Saskatchewan. Figure 3-1 is a map of Saskatchewan. The communities that were sampled at are indicated with circles.

Table 3-1 - Communities chosen for the waste composition study.

Location	Population	Location on Map*
Davidson	1035	C
Big River	809	NW
Shellbrook	1728	NW
Wynyard	1919	EC
Esterhazy	2348	SE
Meadow Lake	2761	NW
Humboldt	5161	EC
Melfort	5559	EC
North Battleford	13693	WC
Swift Current	14821	SW
Moose Jaw	32131	C
Prince Albert	34291	C

***C=central Saskatchewan, NW=northwest, EC=eastern central, SW=southwest, SE=southeast, WC=west central; Locations are relative to the southern half of Saskatchewan**

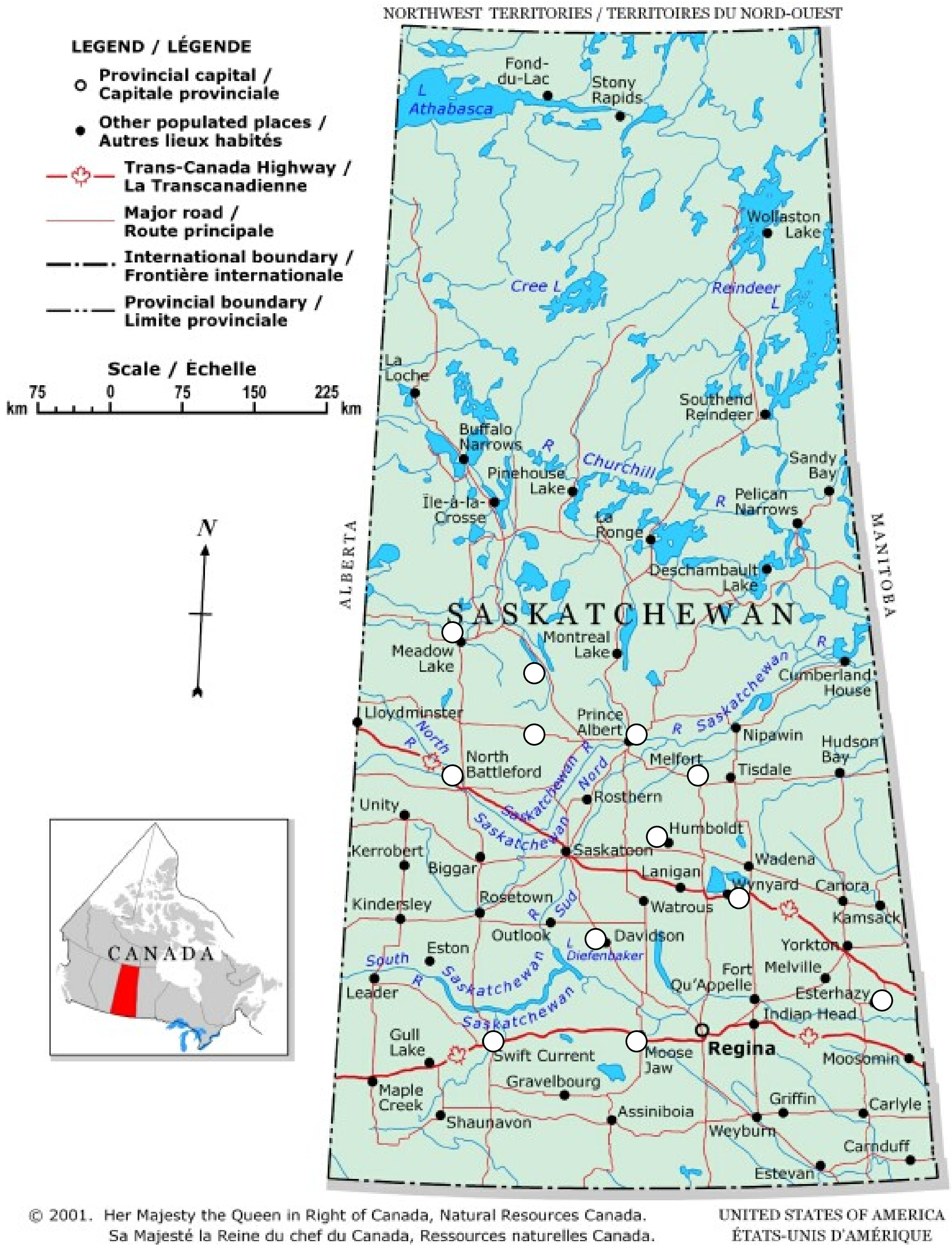

Figure 3-1 - Map of Saskatchewan.*

*Source: Natural Resources Canada, 2001

3.3 Sampling Procedure

The municipal solid waste characterization was performed by site-specific sampling. The materials flow approach was not possible for small cities and towns in Saskatchewan since the number and types of products sold in rural communities is not representative of the waste stream, as many people who live at these locations often travel to larger centres to purchase materials.

Site-specific sampling was performed according to the American Society of Testing and Materials (ASTM) Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste (standard number D 5231) on five occasions. These included two visits to the Swift Current landfill, two to the Humboldt landfill and one to the Shellbrook landfill. Due to limitations in time and manpower, a modified method was developed for use at the remaining sites. Use of the modified method was supported by statistical analysis (discussed in the following section) demonstrating results obtained using the two methods were not statistically different. Table 3-2 defines the two methods used for sampling.

Table 3-2 - Sampling methods.

	ASTM Method	Modified ASTM Method
Number of Samples	5	7
Size of Samples	91 kg or more (200 lb or more)	45 kg or more (100 lb or more)

ASTM suggests the use of 11 sampling categories because many waste characterization studies are used for recycling options of specific materials and determining percentages of specific products is important. In the study performed, only four categories, adopted from Lamborn's (1999) study of landfill gas generation at the Narre Warren Regional landfill in Victoria, Australia, were used: inert, combustible, putrescible, and plastic. Lamborn's "paper" category was replaced by "dry combustible" to include non-paper items such as cardboard and wood. The following components are contained in each category:

- Inert fraction
    - Ferrous
    - Aluminum
    - Glass
    - Other in-organics
- Wet Putrescible
    - Yard waste
    - Food waste
    - Other organic (including textiles)
- Dry Combustible
    - Newsprint
    - Corrugated
    - Wood
- Plastic

These four categories are important for waste-to-energy because the various technological approaches to waste-to-energy use one or more of the last three categories. For all approaches to waste-to-energy, the inert fraction represents material whose energy is unreasonable and which serves only to increase costs by “diluting” the overall waste stream and by potentially requiring processing and removal.

Each landfill was visited at least once between the months of May to August (Table 3-3).

Table 3-3 - Number of times each landfill was visited for sampling.

Location	Number of Visits
Davidson	1
Big River	1
Shellbrook	2
Wynyard	3
Esterhazy	1
Meadow Lake	1
Humboldt	5
Melfort	1
North Battleford	1
Swift Current	5
Moose Jaw	1
Prince Albert	1

ASTM suggests the waste stream should be sampled in each of the four seasons of the year. For this project, sampling four times a year was not possible due to time and manpower constraints. Furthermore, as the purpose of the study was to obtain an estimate of the waste stream in small cities and towns in Saskatchewan and be able to compare small centres to one another, to similar areas in neighbouring provinces, and to urban centres, sampling in the spring and summer was deemed sufficient.

The waste was sampled by taking six 121 L buckets to the landfill site and filling them randomly with fresh municipal waste from one or two municipal waste truckloads. This resulted in samples weighing between 91 kg and 136 kg (200 and 300 lbs). ASTM suggests the use of 91 kg (200 lbs) samples. However, since only four categories were used rather than 12, samples slightly below 91 kg were deemed sufficient for the modified ASTM method; the fewer the categories, the less necessity for large samples (Sfeir *et al.*, 1999).

At each landfill visit where the modified ASTM method was used, seven samples were taken. When the ASTM method was used, and the samples weighed more than 91 kg, five samples were taken. Raw data can be viewed in Appendix A. Five samples were taken based on an equation from ASTM that determines the number of 91 to 136 kg (200 to 300 lb) samples required to achieve a desired level of precision (ASTM, 1998; see Appendix B). When time permitted, more than seven samples were taken. At all visits to each of the landfills, one or two samples were brought back to the lab to be sorted. This was done primarily so that some of the organic fraction could be retained and tested for moisture content. The results of the moisture content found for the putrescible fraction of the waste can be found in the Appendix A. Sorting samples in the lab also allowed for comparison with results of sorting in the field; sampling in the lab did not prove to have different results.

3.4 Statistical Methods

In order to determine whether the data was significantly different from one location to the next, ANOVA analysis, then Tukey-Kramer analysis was performed on the data. An ANOVA (Analysis of Variance), sometimes called an F test, is closely related to the t-test. Whereas the t-test measures the difference between the means of two groups, an ANOVA tests the difference between the means of two or more groups (Georgetown University, 2005). A one-way ANOVA, or single factor ANOVA, tests differences between groups that are classified by only one independent variable. The advantage of using ANOVA rather than multiple t-tests is a reduction in the probability of a type-I error (Georgetown University, 2005). A type-I error is to reject the null hypothesis when it is actually true (Decoursey, 2003). The null hypothesis in this situation is the hypothesis that each group of samples from each location are not statistically different and can be assumed to be from the same population. Making multiple comparisons increases the likelihood of finding something by chance—making a type-I error. One potential drawback to an ANOVA is that you lose specificity; an F test can indicate that a significant difference between groups exists, but does not specify which groups are significantly different from each other (McBean and Rovers, 1998). To find out which groups are significantly different from each other, a post-hoc comparison is employed; the Tukey-Kramer post-hoc analysis was used for this study.

The ANOVA calculations were done using pHstat2, a statistical add-in for Microsoft® Excel. The only input required other than the data itself is the Q statistic. This value can be found from a table when the number of groups and degrees of freedom are known. When the 12 communities were compared, the group size was 12 and the denominator degrees of freedom were 146. When waste composition from Saskatoon was added into the analysis, the group size was 13 and the denominator degrees of freedom were 168. This analysis can be viewed in the Appendix C.

3.5 Economic Analysis

Waste-to-energy technologies can be viable only if they are economically and technically feasible. The economics of waste-to-energy are very much dependent on waste stream composition and quantity. As mentioned in Chapter 2, each form of waste-to-energy utilizes certain components of the waste stream, and therefore these components must be available in sufficient quantities within the waste stream being assessed. The quantity of waste is even more crucial than the composition; without sufficient amounts of waste, recovering capital costs and maintaining and operating a waste-to-energy facility in a cost-effective manner can be unachievable. Data on waste quantity was available for several of the communities that took part in the study (Table 3-4). This data was all self-reported. The communities of Prince Albert, Swift Current and North Battleford have a landfill scale; for communities without landfill scales, the data may not be as accurate.

Table 3-4 - Waste produced per capita per day in some Saskatchewan communities.*

Name	Population	Tonnes/year in 2004	% ICI	Tonnes/ capita/year	lbs/ capita/year	lbs/ capita/day	kgs/ capita/day
MELFORT	5559	6157	35%	1.11	2441.78	6.69	3.03
NORTH BATTLEFORD	13692	17400	30%	1.27	2801.67	7.68	3.48
PRINCE ALBERT	34291	28922		0.84	1859.44	5.09	2.31
SWIFT CURRENT	14821	27000	33%	1.82	4016.25	11.00	4.99
WYNYARD	1919	1486		0.77	1707.18	4.68	2.12
MEADOW LAKE	6202	8000		1.29	2843.76	7.79	3.53
DAVIDSON	1035	1146	60%	1.11	2441.06	6.69	3.03
Average:				**1.17**	**2587.30**	**7.09**	**3.22**

*Saskatchewan Waste Reduction Council, (2005)

The Saskatchewan average for waste produced per capita is 2.2 kg/day (SERM, 1999). The average for the towns in Table 3-4 is 3.2 kg/day; for the towns in Table 3-4 that have scales, the average is 3.7 kg/day. Notably, ICI (industrial-commercial-institutional) waste is included in these values. ICI waste accounts for approximately 35% of total waste (Saskatchewan Waste Reduction Council, 2005). Removing this portion reduces the average waste produced per capita for these communities to 2.24 kg/day, in line with the value estimated by Saskatchewan Environment and Resource Management (SERM). The data SERM was collected in a similar fashion to the data collected presented in Table 3-4, that is by self-reporting by the communities. This data will be used to estimate how much waste may be necessary to make the development of waste-to-energy facilities at Saskatchewan sites economically feasible.

The Federation of Canadian Municipalities (FCM) published a book entitled "Solid Waste as a Resource" in 2004 describing the types of waste-to-energy projects currently underway in Canada and summarizing their important aspects. It also mentions projects that have been attempted, but are no longer in operation. They categorize the waste-to-energy types mentioned in Chapter 2 into three categories (Table 3-5).

Table 3-5 - FCM categories.

FCM Category	Types of Waste-to-Energy Included
Anaerobic Digestion	■ Anaerobic Digestion (both wet and dry, and thermophilic and mesophilic)
Thermal Conversion	■ Rotary kiln incineration ■ Mass burn incineration ■ Starved air incineration ■ Fluidized bed combustion ■ Pyrolysis and gasification ■ Plasma technology ■ Thermo-chemical reduction ■ Refuse derived fuel
Landfilling	■ Landfill gas utilization ■ Bioreactor landfill

The methodology for economic analysis involves considering each of these types of waste-to-energy based on past performance of these systems in Canada, and relates them more specifically to a Saskatchewan context based on waste quantity and composition.

3.6 Summary

Waste quantity and composition are important aspects for determining the feasibility of waste-to-energy alternatives for a given community. This chapter has outlined the protocols used for determining MSW composition at selected locations in Saskatchewan.

The three categories of waste-to-energy under consideration are anaerobic digestion, thermal conversion, and landfill gas utilization. Information on waste quantity and the data collected on waste composition will be used to determine the types of waste-to-energy most economically feasible in small cities and towns in Saskatchewan.

4.0 RESULTS

4.1 Introduction

This chapter gives a breakdown of the findings from the research described in the methodology section. The effects of demographic factors on waste stream composition for the twelve communities that were part of this study will be analyzed. The question of which form of waste-to-energy is most viable in small cities and towns in Saskatchewan will be discussed. This research covered a wide spectrum of communities and waste-to-energy types, so further research will be suggested in certain areas.

4.2 Results of Sampling

Table 4-1 summarizes the waste stream composition as percentage by weight, with each data point the average of five or more samples. Five samples each weighing a minimum of 91 kg (200 lb) were taken using the ASTM method. At least seven samples were taken using the modified ASTM method, weighing no less than 45 kg (100 lb) each.

Table 4-1 - Summary of waste stream composition (% by weight).

City	Inert	Wet Putrescible	Dry Combustible	Plastic
Swift Current	7	51	31	12
Humboldt	7	45	31	16
Wynyard	9	40	36	15
Esterhazy	15	47	24	14
Prince Albert	6	30	45	19
Meadow Lake	4	42	33	21
Big River	13	41	32	13
Moose Jaw	5	46	35	14
Davidson	7	54	28	12
North Battleford	4	57	29	10
Melfort	6	39	37	18
Shellbrook	6	48	32	14
Saskatoon*	7	45	39	9
Average	**7**	**45**	**33**	**15**
Standard Deviation	**3.27**	**6.93**	**5.36**	**3.51**

*Taken from City of Saskatoon Waste Composition Study, May 1998

Figure 4-1 shows the raw waste stream composition data plotted on a graph. The raw data can be viewed in Appendix A.

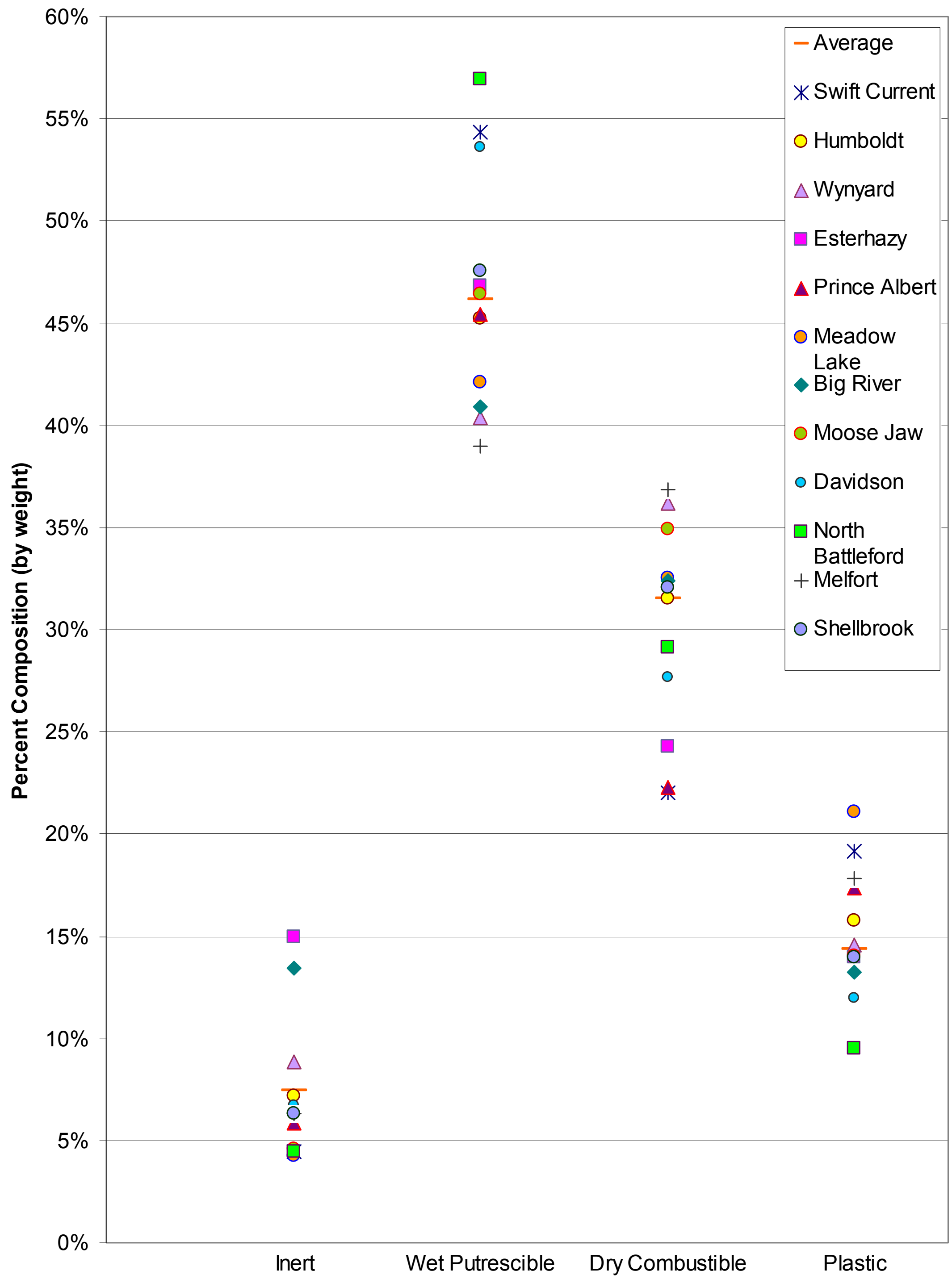

Figure 4-1- Plot of raw waste stream composition data.

The data from the various locations were fairly consistent, and an ANOVA then Tukey-Kramer analysis was performed on the data to determine any significant differences between sites. A detailed breakdown of the statistical analysis can be found in Appendix C. Every location was compared for each of the four fractions of the waste stream, resulting in 264 combinations. Only two combinations were found to be statistically different:

- Swift Current and Prince Albert – Putrescible Fraction
- Prince Albert and North Battleford – Putrescible Fraction

When data from a study in Saskatoon is added to the analysis generating 312 possible combinations, only three were found to be statistically different:

- Meadow Lake and Saskatoon – Plastic Fraction
- Swift Current and Prince Albert – Putrescible Fraction
- Prince Albert and North Battleford – Putrescible Fraction

These results indicate the waste composition in small towns and small cities in Saskatchewan does not in general differ significantly from one community to the next, nor does it differ from the larger centers in the province such as Saskatoon. Table 4-2 compares the Saskatchewan data to waste composition in other locations. Edmonton and Red Deer are cities in Alberta (the neighbouring province to the west of Saskatchewan.) The data from these cities was obtained from a document by GCG Dillon Consulting Ltd., however the composition studies were done by the communities themselves. The region of Stettler is also in Alberta, and its waste composition study was performed by GCG Dillon

Consulting Ltd. The column titled “prairies” in the table is data taken from various small communities in the prairie region (southern part) of Alberta, and was also obtained from GCG Dillon Consulting Ltd.

Table 4-2 - Comparison of data obtained from sampling to other locations in Saskatchewan and Alberta.

	Average from Rural Sask	Saskatoon*	Edmonton**	Red Deer**	Stettler (town)**	Stettler (rural)**	Prairies**
inert	7	7	9	9	9	15	14
wet putrescible	46	45	37	44	37	37	34
dry combustible	33	39	45	41	40	33	45
plastic	15	9	9	6	11	8	6
other	0	0	0	0	3	7	1

*City of Saskatoon (1998)

**GCG Dillon Consulting Limited (1992)

4.3 Correlation of Waste Stream with Demographics

Many studies around the globe have attempted to predict waste stream composition based on demographic factors (e.g., Khan and Burney, 1989; Daskalopoulos *et al*, 1998) . Most of these studies have found correlations between particular demographics and components of the waste stream. Common lifestyle choices of community members falling into certain demographic categories can affect the waste stream. For instance, the lifestyle of senior citizens will differ greatly from a young family with two infants; older people may read more newspapers and magazines, while the families with infants may throw away large quantities of diapers. Personal income may also affect the amount of paper in the waste stream. The demographic factors for each of the communities where waste was sampled (used in Figure 4-2 to Figure 4-9) were obtained from the Saskatchewan Bureau of Statistics.

Daskalopoulos *et al.* (1998) report the amount of paper increases with related total consumer expenditure. Their study was conducted with data from various countries in Europe, and North America. Figure 4-2 shows how the average paper (dry combustible) fraction from each of the Saskatchewan communities sampled varies with average personal income at each community. Personal income was used as a surrogate for consumer expenditure, based on a strong correlation between the two (Daskalopoulos *et al.*, 1998).

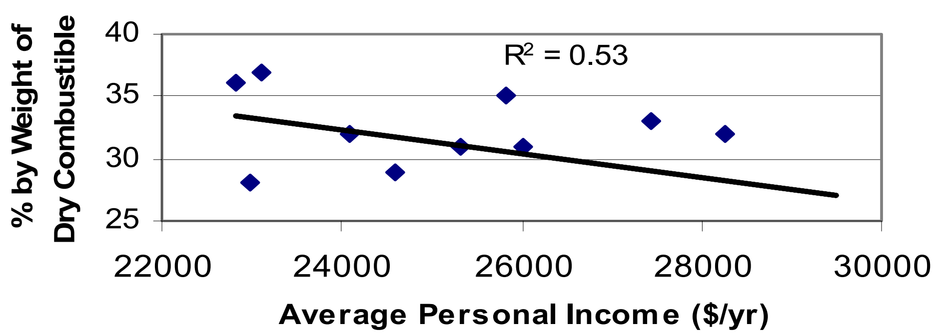

Figure 4-2 - Average dry combustible fraction from Saskatchewan communities sampled (%) versus average personal income ($/year).

The trend line in Figure 4-2 indicates the percentage by weight of dry combustible material in the waste stream slightly decreases with increasing income. This is contrary to the findings of Daskalopoulos *et al.* (1998), but notably the R^2 value is low at 0.53.

Figure 4-3 plots the average inert fraction from each of the Saskatchewan communities sampled versus dwelling occupancy rate. The points appear fairly scattered and the very slight increase in the inert fraction of the waste stream with increasing dwelling occupancy rate is not significant (R^2=0.31). This trend is contrary to results of Khan and Burney (1989), who found that lower occupancy rates resulted in higher percentages of glass; glass is a major component of the inert fraction at roughly 40% by weight. The range in occupancy rates for the locations in the Khan and Burney (1989) study were between 2.4 and 5.7 persons per dwelling. In Saskatchewan, the average range for cities and towns is about 1.95 to 2.75 persons per dwelling. The lower variation in occupancy rates in Saskatchewan may contribute to the lack of a significant trend.

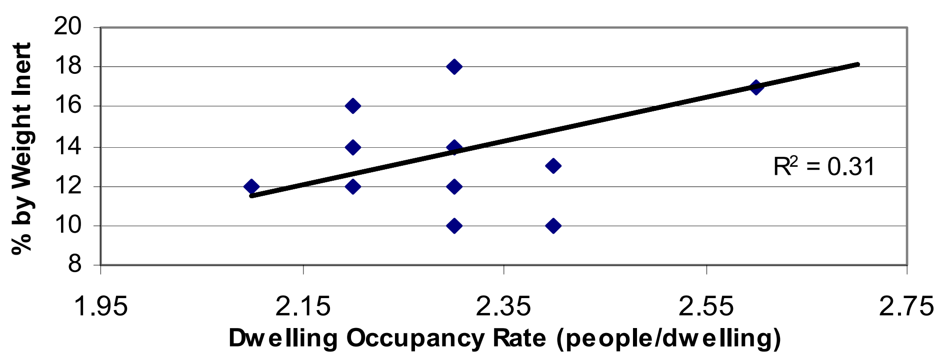

Figure 4-3 - Average inert fraction from Saskatchewan communities sampled (%) versus dwelling occupancy rate (people/dwelling).

Figure 4-4 demonstrates lack of a strong trend between dwelling occupancy rate and the putrescible fraction of the waste stream in Saskatchewan communities.

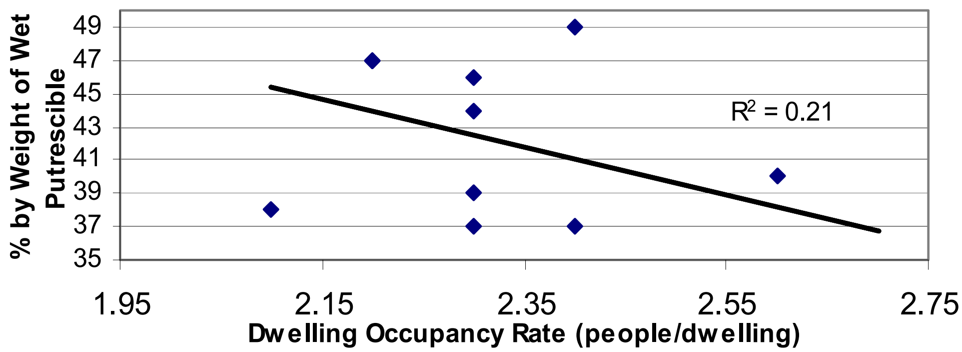

Figure 4-4 - Average wet putrescible fraction from communities sampled (%) versus dwelling occupancy rate (people/dwelling).

Daskalopoulos *et al.* (1998) report that organic fractions decrease with increasing related total consumer expenditure. Figure 4-5 shows how the average wet putrescible fraction from each of the Saskatchewan communities sampled varies with average personal income. The trend line is in agreement with the findings of Richardson and Havelick (1978), however, the R^2 is weak (0.19).

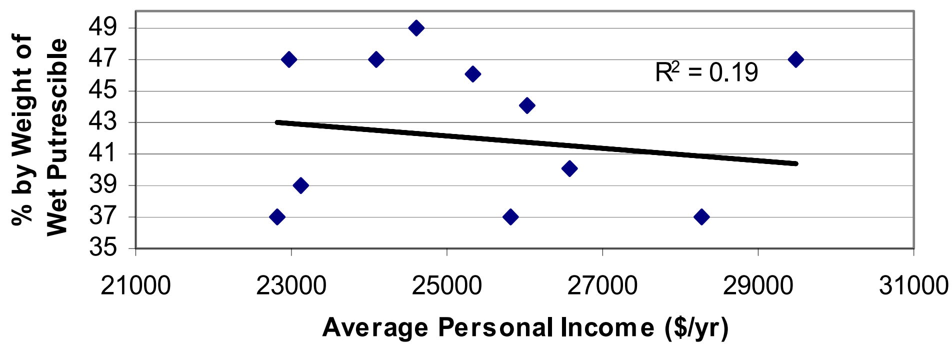

Figure 4-5 - Average wet putrescible fraction from communities sampled (%) versus average personal income ($/year).

Senior citizens are often perceived to waste less than younger citizens. Figure 4-6 tests the notion that the percentage of wet putrescible in the waste stream will decrease as the percentage of citizens over age 65 increases. However, such a trend is not apparent.

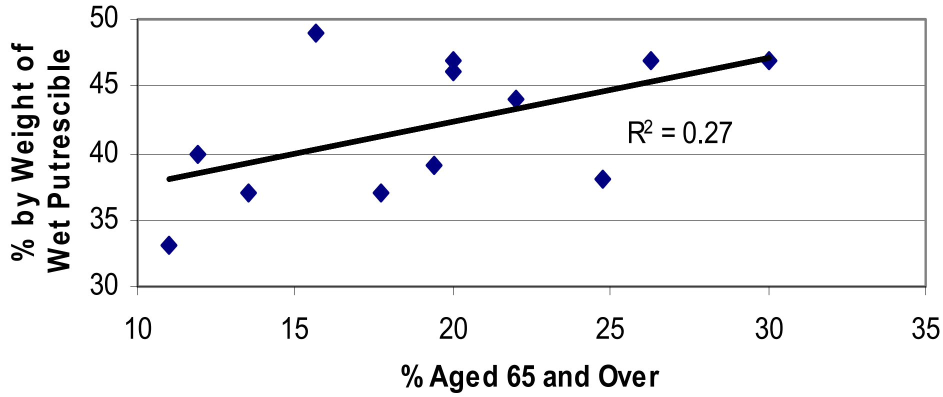

Figure 4-6 - Average wet putrescible fraction from communities sampled (%) versus % citizens 65 years of age and older.

Areas with more senior citizens tend to produce more paper waste since senior citizens read more newspapers than other demographic groups (City of Saskatoon, 1998). Figure 4-7 is a plot of the percentage of dry combustible versus the percentage of citizens over the age of 65 for the Saskatchewan communities sampled, and demonstrates no significant trend between these factors (R^2=0.02).

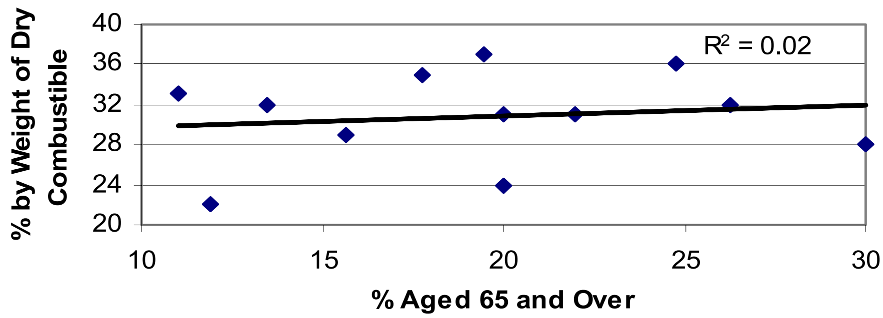

Figure 4-7 - Average dry combustible fraction from communities sampled (%) versus % citizens 65 years of age and older.

The wet putrescible fraction may increase if a community has more land area, due to the increase in yard waste produced. Figure 4-8 is a plot of the putrescible fraction versus land area, and demonstrates no trend between these variables for Saskatchewan communities.

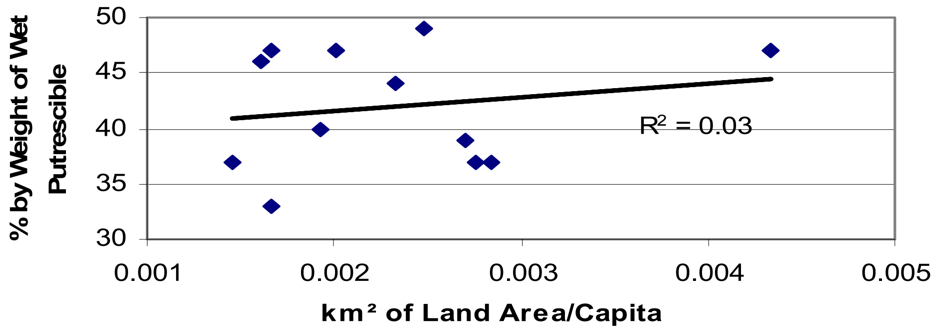

Figure 4-8 - Average wet putrescible fraction from communities sampled (%) versus square kilometres of land area per capita.

Plastic in the waste stream comes primarily from retail stores in the form of packaging. Therefore, the amount of plastic in the waste stream may increase with increasing number of retail stores per capita. Figure 4-9 tests this relationship but shows no trend (R^2=0.07).

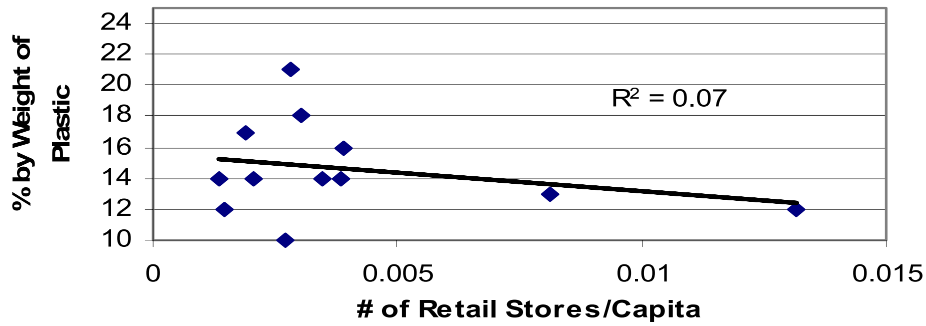

Figure 4-9 - Average plastic fraction from communities sampled (%) versus retail stores per capita

In summary, the waste composition data collected did not show any significant trends with demographic factors. However, when compared to other studies, the trend in the data is generally not any less significant. This is demonstrated in Figure 4-10. The y-axis is the dry combustible fraction of the waste stream. The x-axis is average personal income from the study performed (multiplied by 30 to obtain a similar scale, hollow circles), and the related total consumer expenditure per person per year in the United Kingdom from Daskalopoulos *et al.* (1998) (solid circles).

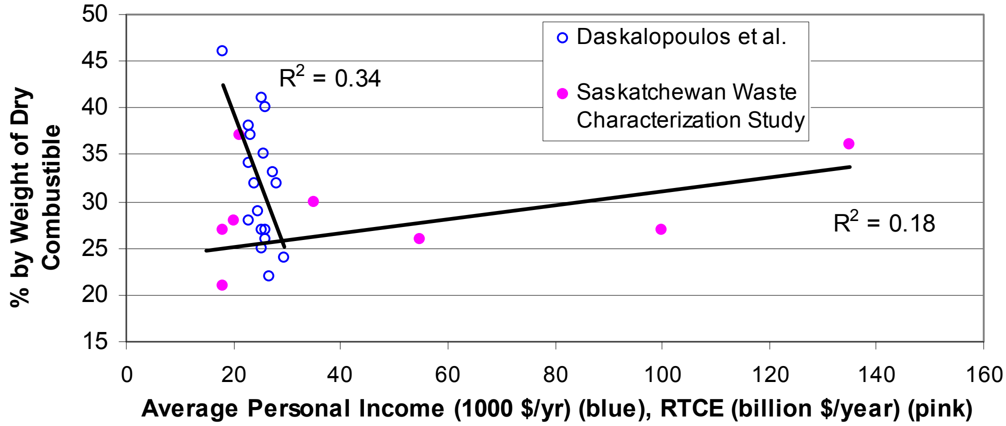

Figure 4-10 - Comparison of % dry combustible vs. personal income (collected data) and RTCE (Daskalopoulos *et al.,* 1998).

4.4 Costs and Feasibility

4.4.1 Anaerobic Digestion

According to the FCM (2004), anaerobic digestion of municipal solid waste is expensive compared to other options for the volumes of waste produced by most Canadian municipalities. Anaerobic digestion is more viable in Europe, where little landfill space exists and environmentally sound incineration is very costly (FCM 2004; Kumar 2000). Anaerobic digestion also is more financially viable in Europe due to higher tipping fees, usually about $150-$200/tonne (CAD). In Saskatchewan, land is of no shortage, and tipping fees are relatively low. Only three anaerobic digesters are currently in operation in Canada, all in Ontario: two in the city of Toronto and one in Guelph. Of note, one of the two in the Toronto area is planning to shut down due to financial trouble, as the owner has not been successful in negotiating with potential customers (FCM, 2004).

Suitability of Saskatchewan Waste

The type of waste used in an anaerobic digester includes the organic waste such as yard waste, food waste and paper. Other components of the municipal waste stream, such as wood, plastic, metal, glass, and textiles are not used in an anaerobic digester because they are not as readily biodegradable. Based upon the waste characterization study performed, the waste in Saskatchewan is composed of approximately 46% putrescible components. A small portion of this is textiles that may not be readily biodegradable; the textile portion was accounted for separately in the waste composition study performed and was found to average ~5% of the total composition. On average the dry combustible materials within the waste stream are ~33%, including a small amount of wood. Wood was also accounted for separately within the dry combustible fraction in the waste composition study and found to be less than 1% of the total waste stream composition. A conservative estimate for the portion of the waste stream in small cities and towns in Saskatchewan that could be utilized for anaerobic digestion is 65%-70%. Municipal solid waste is a heterogeneous mixture that is difficult to separate perfectly. Contamination of the organic waste stream can easily occur, thereafter rendering an entire batch of municipal solid waste indigestible within the anaerobic digester. Anaerobic digestion of bio-solids from wastewater treatment plants is much more popular because it is a homogenous mixture and no careful segregation is required (Kumar, 2000). Saskatchewan does have large amounts of bio-solids wastes from agricultural activities, and these wastes and certain components of municipal solid waste, if combined, may make excellent feedstock for anaerobic digestion. This potential could be researched further.

Feasibility in Saskatchewan Based on Waste Quantity

In Europe, anaerobic digestion plants typically digest between 8,000-15,000 tonnes/year of organic waste from MSW. Kumar (2000) indicates some plants in Europe have been successful with as little as 4,000 tonnes/year. In contrast, Sjoberg *et al.* (1985) found it would be most economical in the United States to have approximately 65,000 tonnes per year of unsorted municipal solid waste for an anaerobic digestion facility, or approximately 42,000 tonnes per year of organic waste. In Saskatchewan, larger centers such as Prince Albert produce about 28,000 tonnes per year of municipal solid waste, approximately 65% of which is organic. Therefore, approximately 18,000 tonnes/year of waste could be anaerobically digested. Thus, based on waste quantity and composition, anaerobic digestion is a possibility in larger rural centers in Saskatchewan. The current trend seems to be towards larger projects (De Baere, 2000), and smaller centres in Saskatchewan would not be able to support a large operation. However, the cost of anaerobic digesters is decreasing with time and the number of facilities that use only municipal waste are increasing (Kumar, 2000), so with time they may become more viable in places such as Saskatchewan.

Summary of Feasibility

Table 4-3 summarizes anaerobic digestion as a waste-to-energy alternative. For small cities and towns in Saskatchewan, it is currently not a recommended form of waste to energy for the following reasons:

- Plants of 10,000 tonnes per year are required (FCM, 2004). Based on the waste produced per capita/year in Saskatchewan, only cities of 9,000 people or more could accommodate an anaerobic digester facility. Only 9 cities in Saskatchewan, including Saskatoon and Regina, have populations over 9,000, (Saskatchewan Bureau of Statistics, 2001).
- The cost decreases significantly when 50,000 tonnes per year are available (FCM, 2004). A population base of about 43,000 is required for this level of waste productions, and only the two major centres of Saskatoon and Regina would be able to realize financial gains based on a slightly larger scale (Saskatchewan Bureau of Statistics, 2001).
- The greatest economic potential for anaerobic digestion is for locations with more than 100,000 tonnes of waste per year (FCM, 2004). This requires a population over 85,000, again eliminating all but the two major centres of Saskatoon and Regina. Therefore, anaerobic digestion could conceivably be economically viable in Saskatoon and Regina, but is not likely to be feasible in any other Saskatchewan community.
- Waste would have to be meticulously sorted, either by the public themselves or by paid workers. This adds costs since contamination of

the organics to be digested cannot be risked for the system to function properly.

- Few plants exclusively use municipal solid waste (Kumar, 2000).

Table 4-3 - Anaerobic digestion summary.*

Factor	Summary
DESCRIPTION	Organic biodegradable waste broken down without oxygen (anaerobic) to produce methane gas, carbon dioxide, water, and digestate (which is composted). Can be wet or dry.
GENERAL PERFORMANCE	Can divert all or most organic and biodegradable products (food, yard waste, some papers)
COMMUNITY CHARACTERISTICS	Anaerobic digestion is a high-tech system that requires skilled technical operators. It is most suited to reasonably large urban areas with at least 18,000 to 40,000 households as a minimum threshold to justify the construction of the system
COSTS	Costs require a plant of at least 10,000 tonnes/year. Costs decrease dramatically towards 50,000 tonnes/yr. Greatest economies of scale at 100,000 tonnes/yr (mixed waste from 180,000 households or source-separated waste from 400,000 hhlds)
FACTORS THAT INFLUENCED ACQUISITION	Availability of local energy
ENVIRONMENTAL EFFECTS	Diverts organic waste from landfill, minimizing generation of acidic leachate and methane Generates methane under controlled conditions, as an energy source, displacing other sources of power
ENERGY IMPLICATIONS	Net energy generator, with 50% (wet plants) to 80% (dry plants) available for export
LESSONS LEARNED	Plants of 10,000 to 20,000 tonnes/yr source-separated organics work well in Europe. Little track record for larger plants currently in operation

*FCM, 2004

4.4.2 Thermal Conversion

As discussed in detail in Chapter 2, most forms of thermal conversion have high capital costs (e.g. Kumar, 2000; Parker and Roberts, 1985; Tchobanoglous et al., 1993). Several different thermal conversion facilities are in use in Canada today. In 1996, 140 municipal solid waste combustion units operated in the United States (Bjeldanes and Beard, 1996). The most popular forms of thermal conversion for municipal solid waste in North America are rotary kiln, mass burn, starved air incineration and fluidized bed (FCM, 2004). Other thermal conversion technologies mentioned earlier are primarily used for hazardous wastes. However, pyrolysis and gasification have been gaining popularity for use with municipal solid waste. Plasma arc and thermo-chemical reduction technologies will not be discussed as part of the cost analysis.

For most thermal conversion technologies, the initial capital costs for equipment and installation are the critical issue. The installation costs can be over 200% of the equipment costs due to the technical expertise required (Neissen, 1995).

Suitability of Saskatchewan Waste

Thermal technologies utilize all components of the waste stream except glass and metal. Based on the waste composition study performed, the inert fraction is approximately 7% of the waste stream on a wet weight basis in small cities and towns in Saskatchewan, leaving 93% which could be directed to these thermal conversion technologies. Therefore the waste stream composition is well suited for thermal conversion technologies that use all but the inert fraction of the waste.

Feasibility in Saskatchewan Based on Waste Quantity

Since the composition of Saskatchewan waste is suitable for use in thermal conversion facilities, waste quantity and costs will be the determining parameters for feasibility. In this and the following section, the information regarding the typical capacities of the facilities and their costs is taken from FCM (2004).

- Rotary Kiln Incinerator

Rotary kiln incinerators have typical capacities ranging from 10 to 50 tonnes per day (FCM, 2004). This aligns with communities between 3,200 and 15,600 people, of which 10 exist in Saskatchewan (Saskatchewan Bureau of Statistics, 2001). For countries other than the United States, Bjeldanes and Beard (1996) report that the rotary kiln incinerators in operation as of 1996 have capacities ranging from 152 to 1090 tonnes/day and averaging 480 tonnes/day. Facilities of this size require a population of ~150,000, and thus would be unsuitable except for Saskatoon and Regina.

- Mass Burn Incineration

These facilities typically range in size from 100 to 1000 tonnes per day (FCM 2004). This waste production rate would require a population of between 31,000 to 310,000; only 4 centres of this size exist in Saskatchewan: Saskatoon, Regina, Prince Albert and Moose Jaw.

- Starved Air Incineration

These facilities range in size from 10 to 100 tonnes per day. This suggests communities with 3,200 to 32,000 residents could support such a facility. Sixteen communities of this size exist in Saskatchewan (Saskatchewan Bureau of Statistics, 2001).

- Fluidized Bed Combustion

Fluidized bed combustors range in size from 50 to 500 tonnes per day. In Saskatchewan this means that communities with between 15,600 and 156,000 residents could possibly support this type of technology. Five communities in Saskatchewan fall into or above this range (Saskatchewan Bureau of Statistics, 2001).

- Pyrolysis and Gasification

Though pilot studies have been done, pyrolysis and gasification systems have yet to be successfully commercially applied to the management of municipal solid waste in North America (FCM, 2004; Kumar, 2000). They are still emerging technologies for use with non-homogeneous materials such as municipal solid waste (Advanced Energy Strategies Inc., 2004). Gasification has been successful in parts of Europe where MSW is segregated by citizens at its source. (Crow *et al.*, 2002). This has not been attempted in North America, where the main reasons for failures of these types of plants has been the heterogeneity of MSW and the difficulty of segregation (Vesilind *et al.,* 2002). If landfill and operating costs increase, and energy prices change in terms of environmental costs, these technologies could become attractive in Canada. However, this type of technology is not currently recommended for small cities and towns in Saskatchewan as follows:

- These technologies have yet to be applied in Canada to municipal solid waste. They are not well understood, and major expertise would be required to run a plant (which would likely not be available in small cities and towns).
- The capital costs of such facilities are quite high, estimated to be between \$30 and \$40 million for a town in Alberta with 20,000 residents (CAEP, 2005). Gasification plants for larger location could cost ten times as much.
- A British company, Organics Ltd., estimated the costs of building a facility in England to be \$7 million (Canadian dollars), with operating costs of \$400,000/year and a revenue of about \$1.5 million a year (Eden, 1999). Payback was estimated at only 2.3 to 3.8 years. This excludes the cost of the front-end separator, and is based on a facility that obtains 100 tonnes per day of waste. This seems quite attractive, but it may be biased by much higher tipping fees and higher energy prices in Europe.

  - Gasification produces more electricity and less greenhouse gases than incineration, but has not been proven at commercial scales (Murphy and McKeogh, 2003).

Summary of Feasibility

Table 4-4 summarizes the feasibility of thermal conversion technologies, two of which are suitable for small cities and towns in Saskatchewan. The costs mentioned are total unit costs, which include both capital and all operating costs.

- Rotary Kiln Incinerator

Rotary kiln incinerators may be a possibility for small cities and towns in Saskatchewan. The technology is relatively capital intensive (Bjeldanes and Beard, 1996; FCM, 2004). Based on what has been done overseas, this technology would not be recommended. However, economics of waste-to-energy are different in Canada and this technology has been successfully utilized on a small scale in Canada. Combined annualized capital and operating costs (net of recovered energy revenue) range from $125 to $150 per tonne of waste processed, estimated over a 25-year capital payback period (FCM, 2004). Rotary kiln incinerator technology applications can meet all Canadian environmental regulatory requirements (FCM, 2004). However, they produce large amounts of ash and some air pollution (Kumar, 2000), control of which can add to the life cycle costs (FCM, 2004). Public perception of such facilities is a further consideration.

- Mass Burn Incineration

Mass burn incineration is not recommended for small cities and towns in Saskatchewan, since the quantity of waste required is larger than what can be provided by all but the four largest centers in the province.

- Starved Air Incineration

Starved air incineration is another possibility for small cities and towns in Saskatchewan. Combined annualized capital and operating costs (net of recovered energy revenue) range from $100 to $150 per tonne of waste processed, estimated over a 25-year capital payback period. This incinerator technology can also meet all Canadian environmental regulatory requirements, and particulate matter emissions are lower than other incineration methods.

- Fluidized Bed Combustion

Fluidized Bed Combustion is not a recommended technology for small cities and towns in Saskatchewan. It has not been widely used, and only one such facility exists in Canada. (FCM, 2004). Also, only two municipalities in Saskatchewan have waste quantities comparable to locations where the technology has been successful. Other disadvantages of fluidized bed combustion include extensive air pollution control equipment, intensive maintenance, and skilled laborers.

Table 4-4 - Summary of thermal treatment.*

Factor	Summary
DESCRIPTION	Waste is broken down to produce heat.
GENERAL PERFORMANCE	Thermal treatment can divert 70 per cent of waste from landfill
COMMUNITY CHARACTERISTICS	Thermal treatment is a high-tech system that requires skilled technical operators. Depending upon the specific technology, it is suitable for communities ranging from small villages to large urban centres
COSTS	Costs will vary depending upon the specific thermal technology used and the operating capacity required
FACTORS THAT INFLUENCED ACQUISITION	The availability of local energy markets is a critical factor in the decision
ENVIRONMENTAL EFFECTS	Thermal treatment has the benefit of diverting waste from landfill and therefore minimizing generation of acidic leachate and methane. It has the added benefit of generating energy, therefore displacing the need to use other sources of power
ENERGY IMPLICATIONS	Thermal treatment is a net energy generator
LESSONS LEARNED	Although technically sound and proven in Canada in terms of environmental and energy considerations, public perception/opposition is such that the siting of new facilities is difficult

*FCM (2004)

4.4.3 Landfill Gas Utilization

Landfill gas utilization, the process of collecting methane gas off of a landfill and utilizing it for energy, has been used at various landfills across Canada. Thorneloe *et al.* (1998) report the number of landfill gas utilization facilities in the Unites States may increase from 200 to 400 within the next several years. A newer technology being attempted at several locations are bioreactor landfills, a process by which moisture is added to speed up the decay processes occurring in a landfill, thus producing more methane.

Suitability of Saskatchewan Waste

Landfills produce methane due to the decay of organic matter. Readily degradable material such as food waste and yard waste is best as paper degrades at a somewhat slower rate (Kumar, 2000). Plastic is even less readily degradable. The inert fraction of the waste stream is not degradable, so is not desired in a landfill where methane gas is to be collected. In Saskatchewan, the waste stream has a high amount of organic waste; approximately 65% is readily degradable, with only 7% inert. Therefore, the composition of Saskatchewan waste is well suited for landfill gas utilization.

Feasibility in Saskatchewan Based on Waste Quantity

Environment Canada (2005a) lists 17 of the several locations in Canada where methane gas from landfills is being utilized for energy as of 2002. Of those listed, the waste in place ranges from 1.5 million tonnes to 36 million tonnes. All of the facilities are profitable, though the larger ones obtain more revenue. In Saskatchewan, one person produces 0.8 tonnes of municipal waste per year, based upon a production rate of 2.2 kg/day/person (SERM, 1999). By using this values, and the population of Prince Albert (approximately 34,000), a city the size of Prince Albert could produce 1.5 million tonnes of waste in 54 years. However, if ICI waste is included, this time is reduced to approximately 35 years. Small centres with old landfills that have been covered well (which minimizes gas release) may be able to support a landfill gas facility even though the waste produced per day by the community may be small compared to larger centres.

Summary of Feasibility

Landfill gas facilities are feasible in small cities and towns in Saskatchewan. They require very little capital cost compared to other technologies, and utilize waste that has already been disposed. Such facilities are possible even with small amounts of waste if nearby buildings can use the energy generated from the methane directly (E.H. Hanson, 1991). Table 4-5 summarizes landfilling.

Table 4-5 - Landfilling summary.*

Factor	Summary
DESCRIPTION	Waste placed in a landfill breaks down over time due to biological, physical, and chemical processes Emerging technologies, such as bioreactor landfills, may offer more sustainable approaches to landfill disposal of wastes
GENERAL PERFORMANCE	A wide range of performance is available. Individual facilities are custom designed and constructed to meet desired waste management objectives
COMMUNITY CHARACTERISTICS	Landfill disposal of waste is a necessary element of an integrated approach to waste management in all Canadian communities
COSTS	Costs can vary significantly depending upon waste input rates and characteristics, site-specific conditions, regulatory requirements, size of facilities and economies of scale, design and construction requirements, and local/regional competition from other landfills
FACTORS THAT INFLUENCED ACQUISITION	Low costs relative to other options. Limitations on availability of other alternatives
ENVIRONMENTAL EFFECTS	Individual facilities are custom designed and constructed on a site-specific basis to mitigate potential environmental impacts within the context of compliance with applicable regulatory requirements and to meet environmental objectives
ENERGY IMPLICATIONS	The primary energy implication associated with landfill disposal of wastes is the potential to recover energy from the wastes through collection and utilization of landfill gas. Use of energy from landfill gas provides supplementary greenhouse emission reduction benefits by avoiding consumption of the fossil fuels that would otherwise be required to produce an equivalent amount of energy
LESSONS LEARNED	Landfill disposal of waste has evolved significantly from historic practices. Elements of siting, design, and construction of a contemporary landfill site are generally determined on a site-specific basis with the fundamental context being to manage potential environmental risks within the framework of applicable regulations Opposition to landfill facility establishment (siting new facilities and/or expanding existing facilities) from local community and environmental interest groups is the largest single barrier to realizing this component of a municipality’s waste management system

*FCM (2004)

4.5 Decision Analysis

Decision analysis, a technique used to aid decision-making, was performed to determine which type of waste-to-energy is the most viable in small cities and towns in Saskatchewan. In decision analysis, the information relevant to the problem and the uncertainty surrounding the problem is systematically represented and examined. In this case, the uncertainty lies in the waste composition, quantity and costs associated with maintaining each type of waste-to-energy facility for a small city or town.

The four choices considered for waste-to-energy were:

- Anaerobic digestion
- Thermal conversion
- Landfill gas utilization
- None

The option of doing nothing must be considered as this may be the wisest choice if none of the other options prove to be feasible.

The different types of technology are affected by the amount of biomass in the waste stream, since none of them utilize the inert portion. The amount of biomass is affected by the waste produced per capita and the waste composition. Each form of waste to energy will result in a certain amount of energy produced, and will procure certain costs, including:

- Start up costs (also called capital and commissioning costs)
- Operations and maintenance
- Decommissioning costs

- Environmental implications

The start up costs will differ for all of the different waste-to-energy technologies, as will the operations and maintenance costs. The decommissioning costs were assumed to be fairly similar for each of the technologies; since waste-to-energy is a fairly new practice, very little information is available on potential decommissioning costs. Putting a cost on the environmental implications of waste-to-energy technologies is difficult and will not be attempted here. Since all the technologies can be built to regulation standards, the extra costs associated with bringing their pollution control within these standards is already factored into the price. The costs, subtracted from the revenues, equals the potential profits from each type of technology, which in our study are the final measure of which type of waste-to-energy is best. Environmental impacts will also be considered.

Costs and revenues are not easy to obtain since most companies will not share with the public such information about their projects. Costs and revenues were found for some of the projects in operation today in Canada (Table 4-6 to Table 4-8) show the costs for each type of technology. This demonstrates how the costs change in relation to the tonnes/day processed into energy at the facility. The costs are the actual total unit costs, including all capital, maintenance and operation costs. This allows for a truer net cost comparison on an equitable basis between projects with high capital and low operating costs, and those with low capital but high operating costs (Neissen, 1995). Data could not be acquired for sizes of facilities. Some values were extrapolated from the available data, assuming a linear trend between cost per tonne of waste processed and the tonnes of waste per day processed.

Table 4-6 - Anaerobic digestion costs.

tonnes/day	cost ($)/tonne	Source
30	180	FCM, 2004
140	100	FCM, 2004
270	80	FCM, 2004

Table 4-7 - Thermal treatment costs.

Type of Thermal Treatment	tonnes/day	cost ($)/tonne	Source
Kiln Incinerator	10	150	FCM, 2004
	50	125	FCM, 2004
	90	100	FCM, 2004
Mass Burning	400	85	FCM, 2004
	850	65	FCM, 2004
Starved Air Incinerator	0.5	200	FCM, 2004
	3	72	FCM, 2004
	140	100	FCM, 2004
Fluidized Bed	50	110	FCM, 2004
	500	80	FCM, 2004
Refuse Derived Fuel	500	25	FCM, 2004
	500	100	FCM, 2004
Gasification/Pyrolysis	600	100	FCM, 2004
	71	408	FCM, 2004
	71	360	Earth Tech, 2005
	71	806	Earth Tech, 2005
	71	57	Earth Tech, 2005

Table 4-8 - Landfill gas costs.

tonnes/day	cost ($)/tonne	Source
274	-1	E.H. Hanson, 1991
360	-3.55	Environment Canada, 2005a
550	4.6	Environment Canada, 2005a
1230	-0.25	Environment Canada, 2005a

In the above tables, the incurred costs and revenues are combined into one value in units of \$/tonne. For landfill gas generation, waste already in place and producing methane is included as part of the energy produced. Waste already in place is not used for any of the other waste-to-energy types, thus giving landfill gas and advantage in the comparison to other alternatives. However, the cost/tonne for landfill gas utilization varies within a total range of only ~\$8/tonne, between revenues of \$3.5/tonne and costs of \$4.6/tonne. If landfill gas utilization was at its most expensive because of very little waste in place, it would still cost significantly less than the other forms of waste to energy. All costs associated with each type of waste-to-energy are taken into consideration, including the operations and maintenance costs and capital costs. The capital costs are amortized over a 25-year period. FCM (2004) data were already in this form; for other sources, an interest rate of 8% was used to calculate the payments over 25 years. For the decision analysis, the value of 79 tonnes/day was used, which is the approximate tonnage/day for the city of Prince Albert, Saskatchewan. This location was chosen because, aside from Saskatoon and Regina, it is one of the larger centres in Saskatchewan where a waste-to-energy facility is more likely to be feasible. From the data, costs of waste-to-energy options for 79 tonnes/day waste generation are (negative values indicate costs while positive values indicate revenues):

Anaerobic digestion: -$140/tonne

Thermal conversion: -$85/tonne (starved air incineration)

Landfill gas utilization: $2/tonne

Once inputted into DPL (Professional Decision Analysis Software), the best solution is indicated within the policy tree produced (Figure 4-11). For the conditions chosen, landfill gas utilization was found to be the only type of waste-to-energy to produce a profit during the 25 year amortization period. Bioreactor landfills may prove to be even more cost effective than simple landfill gas collection, but no costs were available since few are in operation. Compared to conventional landfills, the total investment of the leachate re-circulation system associated with a bioreactor landfill could be offset by savings in landfill space (Pohland, 1996) and increased energy production due to faster decay of degradable materials.

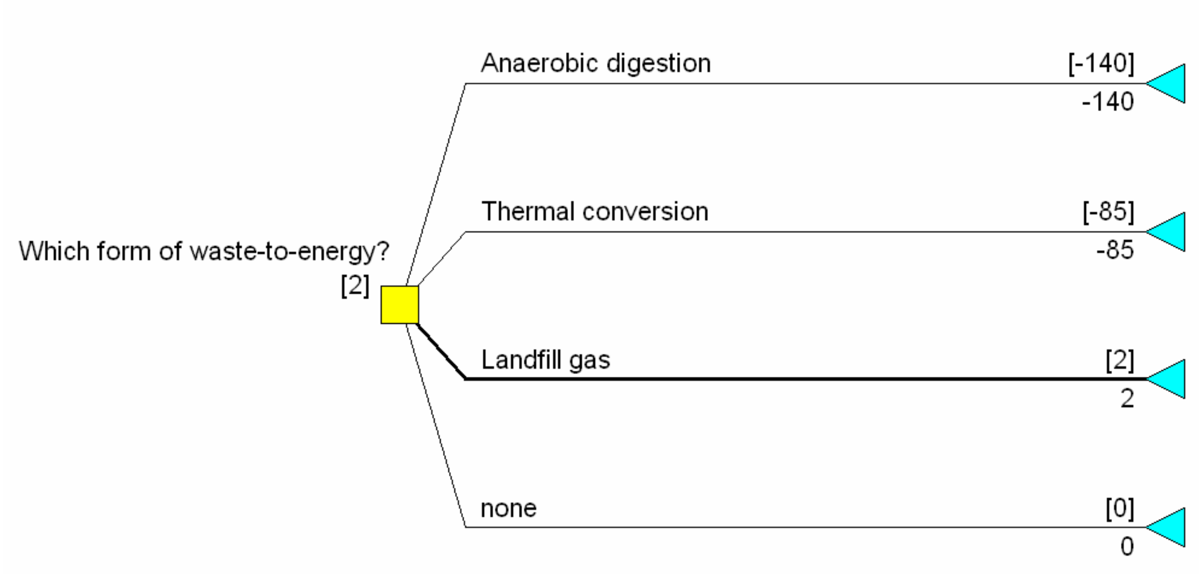

Figure 4-11 - Policy tree for "which type of waste-to-energy is most viable in Saskatchewan?"

4.5.1 Tax Credits

The government of Canada provides taxpayers an accelerated write-off for certain equipment designed to produce energy in a more efficient way or to produce energy from alternative renewable sources (Government of Canada, 1998). Taxpayers can deduct the cost of eligible equipment at up to 30% per year, on a declining balance basis. Electricity generation systems, including certain cogeneration and specified-waste fuelled electrical generation systems are eligible. All types of waste-to-energy would be eligible for these tax breaks. If heat recovery systems are added to the waste-to-energy systems to utilize heat produced during the waste-to-energy process that would otherwise be wasted, these systems are eligible for the same accelerated tax write-off.

4.6 Environmental Impact

Each type of waste-to-energy has different effects on the environment. All can be built to meet Canadian regulatory requirements and environmental standards, however, not all are considered “green” energy. Landfill gas utilization (and bioreactor landfills), anaerobic digestion, and gasification and pyrolysis are considered green energy alternatives; rotary kiln, mass burn, starved air incineration and fluidized bed construction are not (CAEP, 2005; Environment Canada, 2005b). However, in comparison to the use of coal, natural gas, or oil, these technologies would be considered much more “green” (Murphy and McKeogh, 2003).

4.6.1 Landfill Gas Utilization (and Bioreactor Landfills)

Landfill gas utilization and bioreactor landfills utilize methane gas that would otherwise be released into the atmosphere. Due to current and future regulatory reporting requirements, the “credits” that can be provided by trapping and utilizing greenhouse gasses from landfills may become more valuable (Environment Canada, 2005b). Landfills themselves can have environmental impacts, such as soil and groundwater contamination; however, with proper siting and design of the containment system, this impact can be minimal or non-existent.

4.6.2 Anaerobic Digestion

Anaerobic digestion is the most environmentally friendly option for the organic portion of waste as it can be designed to have no negative impacts on the environment. The sludge leftover from the process can be used as compost if the process is done properly, and methane gas can be collected from the organic matter as it decays, thus reducing greenhouse gas emissions in a similar fashion to landfill gas utilization (Kumar, 2000).

4.6.3 Thermal Technologies

For thermal technologies, environmental control systems on average constitute between one third and one half of a facility's total capital and operating cost (FCM, 2004).

4.6.4 Gasification and Pyrolysis

Gasification and pyrolysis are considered green technologies, but produce air pollution and residues that require expensive equipment for reduction to very low levels (Parker and Roberts, 1985).

4.6.5 Rotary Kiln, Mass Burn and Starved Air Incineration

These technologies are considered together because they all produce air emissions and solid residues. None burn as cleanly as gasification and pyrolysis (FCM, 2004).

4.6.6 Fluidized Bed Combustion

This type of thermal technology produces more fine ash in the air pollution it generates than the other technologies mentioned, and thus requires extensive air pollution control systems. However, the solid ash that is produced is of better quality (FCM, 2004).

4.6.7 Rating Environmental Impacts

Based on the total savings of greenhouse gas emissions, Murphy and McKeogh (2003) compared three technologies: incineration, gasification and biogas production (anaerobic digestion). They found that biogas was the most “green”, followed by gasification then incineration. Greenhouse gas emissions are a good measure of environmental impact, but other wastes such as the ash produced from combustion and incineration processes are also produced. Based on greenhouse gas emissions as well as the residues produced, the ranking of technologies considered here from least to most impact on the environment is:

1) Anaerobic digestion
2) Bioreactor landfill and landfill gas utilization
3) Gasification and pyrolysis
4) Fluidized bed combustion
5) Rotary kiln, mass burn and starved air incineration

Anaerobic digestion is most favourable since it eliminates the greenhouse gas emissions that would have been produced from the decaying organic matter. Furthermore, the sludge if composted properly can become a useful fertilizer. Bioreactor landfills and landfill gas utilization are next since the end result of the degraded organic waste remains in the landfill and is not utilized. Bioreactor landfills could be considered somewhat more environmentally friendly, since the leachate produced is re-circulated, resulting in reduced chances for percolation into the groundwater and soil below the landfill. However, for well designed landfills, this is typically not a concern. Gasification and pyrolysis burn cleaner than other incineration technologies, and produce less ash residue. Fluidized bed combustion produces less ash residue than the incineration technologies mentioned, but more air pollution than gasification and pyrolysis. Rotary kiln, mass burn, and starved air incineration produce more air pollution and more hazardous ash residues than all the technologies mentioned.

4.7 Most viable form(s) of Waste to Energy

Of the several different forms of waste to energy discussed, only some are viable economically in small cities and towns in Saskatchewan. The costs associated with each type of waste-to-energy are directly related to the composition of the waste stream, and even more so to the quantity of waste being produced. Another important consideration for determining feasibility was the type of technology used; technologies not yet in commercial use in Canada were not considered feasible. Although costs are the primary factor for determining which type of waste-to-energy is the best choice, environmental effects must be considered separately, since putting a price on damage done or not done to the environment is not possible. The costs and environmental effects were discussed earlier in Chapter 4, with waste stream and composition as major factors under consideration.

Of the seven waste-to-energy alternatives considered, pyrolysis/gasification was eliminated due to its status as an emerging technology. Anaerobic digestion, mass burn incineration, and fluidized bed combustion were eliminated for reasons including economy-of-scale and technical considerations, as discussed earlier in Chapter 4. The remaining three technologies – rotary kiln incineration, starved air incineration, and landfill gas utilization/bioreactor landfills – may be viable for small Saskatchewan cities and towns. The recommendations for waste-to-energy in small cities and towns in Saskatchewan are as follows:

- Landfill gas utilization is the cheapest, most environmentally friendly, and considered the best choice of waste-to-energy for small cities and towns in Saskatchewan.
- Starved air incineration is the second best option, being slightly more expensive, and producing more pollution than landfill gas utilization.
- Rotary kiln incineration is the third best option, being slightly more expensive than starved air incineration, and likewise producing pollution in the form of gases and ash residues.

4.8 Suggested Further Research

Determining which type of waste-to-energy is most viable in small cities and towns in Saskatchewan is a very broad question. It encompasses waste composition, quantity, demographics, economics, and the environment, among other things. If a waste-to-energy facility is seriously under consideration for a particular community, several things should be considered:

- The waste composition study was performed in 2 seasons and with one to five visits to each community. Waste composition is crucial when deciding whether or not waste-to-energy will feasible. Conducting another more thorough waste stream composition study that involves all four seasons of the year may be necessary. This would be especially important in five or ten years from now when the waste stream may be different.
- A community considering the construction of a waste-to-energy facility should partake in a serious attempt to determine as accurately as possible the quantity of waste going into the landfill.
- In the future, additional waste-to-energy alternatives may be proven viable at a commercial scale.
- Research into governmental support that may be provided when developing a waste-to-energy facility may prove to be very beneficial. The government is becoming increasingly supportive of those technologies that fit their definitions of “green” energies.
- Public perception should be researched before building a waste-to-energy facility, and public education programs may be necessary.
- Since landfill gas utilization was found to be the most viable form of waste-to-energy, and bioreactor landfills have advantages over simple landfill gas extraction, more research into bioreactor landfills would be beneficial, particularly in a prairie setting similar to Saskatchewan.

4.9 Summary

Based upon the data gathered on waste stream composition in small cities and towns in Saskatchewan, no relation between the demographics of Saskatchewan communities and the type of waste produced appears to exist.

The most viable forms of waste-to-energy for small cities and towns in Saskatchewan were, in order, landfill gas utilization, starved air incineration and rotary kiln incineration.

If a waste-to-energy facility is being considered, more research must be done on the waste composition and quantity of the community, governmental support that may be available for the project, and the public perception. Waste-to-energy alternatives that are currently unproven on a commercial level may become possibilities for small cities and towns in Saskatchewan in the future.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides the conclusions of the research. It also summarizes the contributions of the findings to the existing body of knowledge on the subject of waste composition and quantity in small cities and towns in Saskatchewan, and the feasibility of waste-to-energy in such a region. The chapter concludes with recommendations for further research.

5.2 Conclusions

The waste composition in small cities and towns in Saskatchewan was found to consist of approximately 7% inert, 45% wet putrescible, 33% dry combustible, and 15% plastic. The following conclusions can be drawn from the waste composition study:

1. The waste composition in small cities and towns in Saskatchewan does not vary significantly from community to community, regardless of differences in demographics and socio-economic factors. This may reflect the modest range of the demographic factors across the province when compared to the broader range found across larger geographic areas such as entire countries or continents.
2. Waste composition in small cities and towns in Saskatchewan is not statistically different from waste composition in the larger Saskatchewan centres.

3. The composition of waste in rural Saskatchewan contains a significant amount of wet putrescible and dry combustible waste (46% and 33% respectively). These components of MSW are generally the most valuable for waste-to-energy processes.
4. Based upon an evaluation of the quantity and composition of waste available in rural Saskatchewan, the following forms of waste-to-energy are technically feasible and are likely to be the most economically viable forms for rural Saskatchewan that are currently available:
    a. Landfill gas utilization
    b. Starved air incineration
    c. Rotary kiln incineration
5. Based upon a screening level evaluation, and taking into account waste composition and quantity, landfill gas utilization is the form of waste-to-energy likely to be the most cost effective and environmentally friendly option (will result in the least amount of air pollution and water pollution). This conclusion is based upon the performance of each of the waste-to-energy techniques, considered in a Canadian context, and by relating them more specifically to how they would likely perform in Saskatchewan based on waste quantity and composition.

5.3 Summary of Contributions

Waste composition in rural Saskatchewan has never before been studied. This important knowledge can be used by other researchers as well as the public to determine the feasibility and successfulness of waste management strategies in rural Saskatchewan and similar areas.

This study has shown that waste does not vary significantly between the communities sampled. This finding makes comparing community waste management strategies possible for waste management planners in rural Saskatchewan communities, and possibly also for other planners in other parts of Canada or internationally. It may also suggest that for waste within a geographic area such as a single province, significant variation in composition may not be expected relative to the inherent variability in the data collected.

A preliminary analysis suggests that certain approaches to waste-to-energy may be possible in rural Saskatchewan based upon the quantity and the composition of the waste available. This research confirms that municipalities should not ignore the opportunity to utilize their municipal solid waste as a resource for energy conversion, as it may be economically beneficial even in smaller centres.

5.4 Recommendations

This study was performed for small cities and towns in Saskatchewan, and no other such studies have been performed on such a widespread basis in other Canadian provinces. In order to determine if this research can be applied to all other similar communities, this type of study should be performed in other locations similar in area and population to that of Saskatchewan.

Small urban and rural areas have, as this research has shown, become very similar to larger urban areas in terms of the products they consume, and therefore the waste that is generated. However, as the products available for consumers change, the waste composition in both rural and urban areas will change. The research done here provides a basis for communities to begin considerations for waste-to-energy alternatives. However, to follow through with implementation of waste-to-energy in a small Saskatchewan community, several things must be accomplished:

- A detailed study of the waste stream in that community for all four seasons of the year, along with a detailed study of waste production rates.
- A reconsideration of all the types of waste-to-energy discussed here, as well as any new technologies.
- Education of the public on the associated benefits of waste-to-energy in order to ensure cooperation amongst all community members.

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Appendix A

Raw Data (Digital Format)

Appendix B

ASTM Calculation for Number of Samples

Calculation for Number of Samples Required

The equation to calculate the required number of samples according to ASTM is given by:

$$n = (t \cdot \frac{s}{e \cdot \tilde{x}})^2$$

where:

n = number of samples

t = student t-statistic corresponding to desired level of confidence

s = estimated standard deviation of governing component (%)

e = desired level of precision (%)

x = estimated mean of governing component (%)

$$n = ?$$
$$t_0 = (n = \infty) \therefore 1.645$$
$$s = 0.11$$
$$e = 0.35$$
$$\tilde{x} = 0.3$$

- The t statistic is found initially at n = infinity
- The standard deviation is the sum of the standard deviations of the components within the governing component (dry combustible). To add standard deviations: $\sigma = \sqrt{\sigma_1^{\ 2} + \sigma_2^{\ 2} + ...}$

  Where σ_1 is the standard deviation of the first component, σ_2 is the standard deviation of the second component, and σ is the standard deviation of the total.

- The level of precision is taken to be 35%, or 0.35.
- The mean of the components within the dry combustible category, as estimated by ASTM, is 3%, or 0.3.

The value of n_0 is calculated, at first, with a t_0 value of 1.645. When n_0 is found with that value, the value of t_1 is found from the table with the calculated value of n_0. From this, a new t, t_1 is found. Then n is recalculated with t_1 to find n_1. If those n_0 and n_1 are not within 10% of each other, t_2 is selected from the table with the value of n_1, and n_2 is calculated. This process is repeated until two consecutive n's are within 10% of each other. The calculation is as follows:

$$n_0 = \left((1.645) \cdot \frac{(0.11)}{(0.35) \cdot (0.3)} \right)^2$$
$$n_0 = 2.97 \therefore t_0 = 2.920$$
$$n_1 = 9.36 \therefore t_1 = 1.86$$
$$n_2 = 3.80 \therefore t_2 = 2.353$$
$$n_3 = 6.07 \therefore t_3 = 2.015$$
$$n_4 = 4.46 \therefore t_4 = 2.353$$
$$n_5 = 6.08 \therefore t_5 = 2.015$$
$$n_6 = 4.46, \therefore t_6 = 2.353$$
$$n_7 = 6.08 \therefore t_7 = 2.025$$
$$n = 5.27$$
$$\therefore n = 5$$

Five 200 lb samples are needed to meet ASTM standards.

Appendix C

Description of Statistical Analysis

Description of Statistical Analysis

- A waste composition study was completed between June 2005 and August 2005 at twelve communities in the province of Saskatchewan.
- Between seven and 32 samples were obtained from each community, weighing at least 100 lbs each.
- The waste composition found for each location is shown in Table 1:

Table 1: Summary of Findings

Location Number	City	Number of Samples (all >100 lbs, some >200 lbs)	Inert	Wet Putrescible	Dry Combustible	Plastic
1	Swift Current	32	7%	51%	31%	12%
2	Humboldt	31	7%	45%	31%	16%
3	Wynyard	24	9%	40%	36%	15%
4	Esterhazy	7	15%	47%	24%	14%
5	Prince Albert	7	6%	30%	45%	19%
6	Meadow Lake	7	4%	42%	33%	21%
7	Big River	7	13%	41%	32%	13%
8	Moose Jaw	7	5%	46%	35%	14%
9	Davidson	7	7%	54%	28%	12%
10	North Battleford	7	4%	57%	29%	10%
11	Melfort	7	6%	39%	37%	18%
12	Shellbrook	12	6%	48%	32%	14%
	Average	**13**	**7%**	**45%**	**33%**	**15%**
	Standard Deviation		**3.41%**	**7.24%**	**5.30%**	**3.27%**

Figure 1 is the data from Table 1 presented graphically. Each number on the x-axis represents a location, as shown in the first column in Table 1.

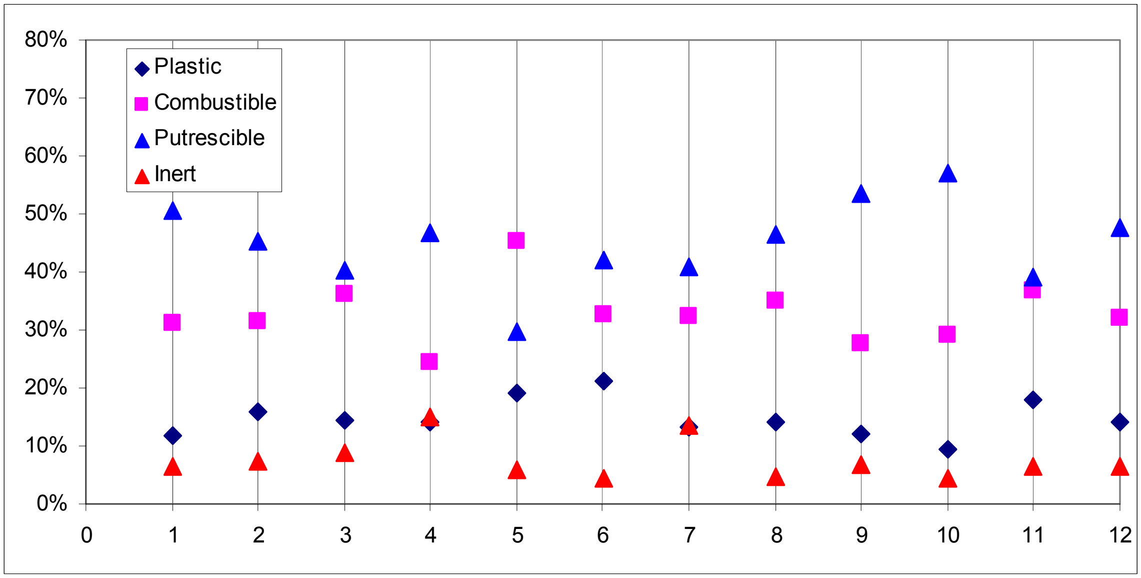

Figure 1: Waste Composition at Each Location (Mean of Samples) vs. Location

Figure 2 is a plot of the composition of every individual sample from each location.

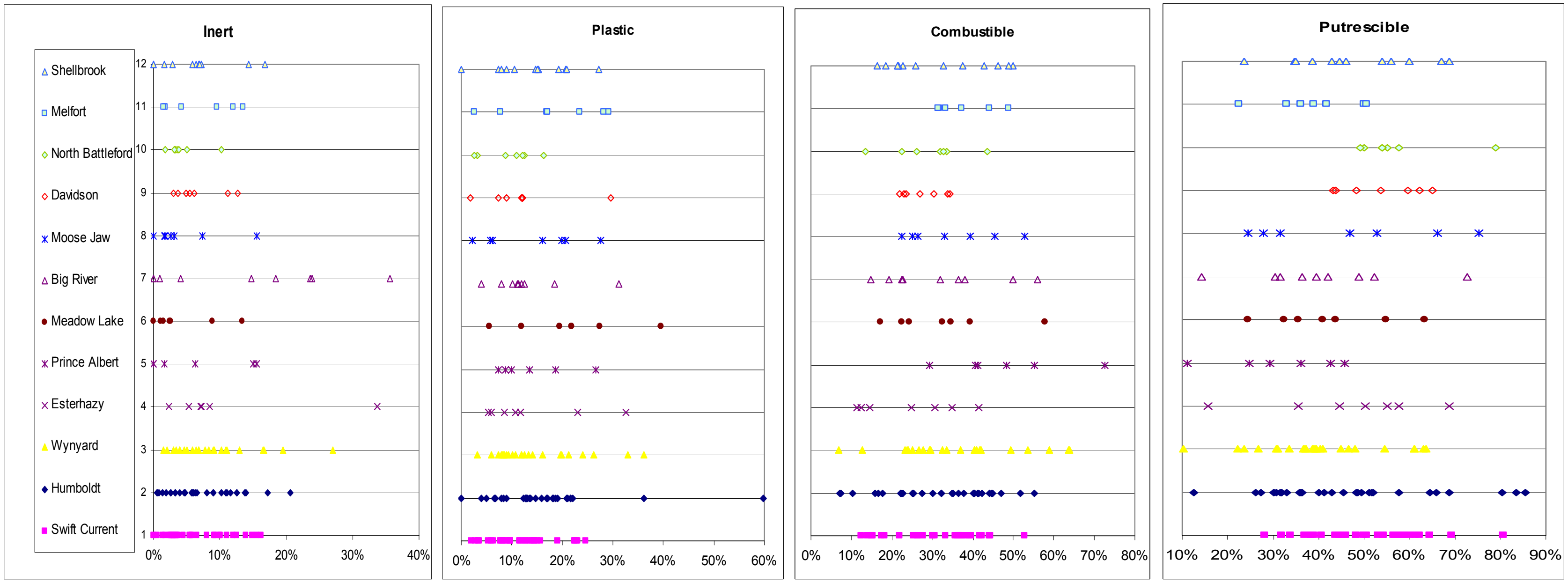

Figure 2: Location vs. Composition of Every Sample

- **Question**: Is the waste composition between each of the communities significantly different?
- How can this be determined?
    - ANOVA followed by Tukey-Kramer analysis.
- What is ANOVA?
    - ANOVA (Analysis of Variance), sometimes called an F test, is closely related to the t-test.
    - However, where the t-test measures the difference between the means of two groups, an ANOVA tests the difference between the means of two or more groups.
    - A one-way ANOVA**,** or single factor ANOVA, tests differences between groups that are only classified on one independent variable (in this case it would be the composition- i.e.: inert, dry combustible, etc.)
    - The advantage of using ANOVA rather than multiple t-tests is that it reduces the probability of a type-I error.
        - A type-I error is to reject the null hypothesis when it is actually true
        - The null hypothesis in this situation is the hypothesis that each group of samples from each location are not statistically different and can be assumed to be from the same population.

        - Making multiple comparisons (as is done with multiples t-tests) increases the likelihood of finding something by chance—making a type I error.
    - Disadvantage of ANOVA: you lose specificity. All an F tells you is that there is a significant difference between groups, not which groups are significantly different from each other
    - Remedy: Post hoc comparison such as Tukey-Kramer
- What is Tukey-Kramer Analysis?
    - For the Tukey method the minimum significant difference is calculated for each pair of means. If the observed difference between a pair of means is greater than the minimum significant difference, the pair of means is said to be significantly different
    - Uses the studentized range distribution (Q- statistic)
    - When one has unequal sample sizes, Tukey-Kramer is used.
- How is the Q- Statistic found?
    - It is found using a table, with known values of k (number of groups of samples for Tukey Kramer).
    - For the data in this study, the number of groups is 12.
    - The degrees of freedom used to find the Q statistic are calculated by the Tukey Kramer Method. The denominator degrees of freedom are used.
    - Table 2: shows the values of the Q statistic for various group sizes.

Table 2: Table for Determining Q Statistic (Studentized Range Distribution)

Number of Groups

Degrees of Freedom	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	18	27	32.8	37.2	40.5	43.1	45.4	47.3	49.1	50.6	51.9	53.2	54.3	55.4	56.3	57.2	58	58.8	59.6
2	6.09	8.33	9.8	10.89	11.73	12.43	13.03	13.54	13.99	14.39	14.75	15.08	15.38	15.65	15.91	16.14	16.36	16.57	16.77
3	4.5	5.91	6.83	7.51	8.04	8.47	8.85	9.18	9.46	9.72	9.95	10.16	10.35	10.52	10.69	10.84	10.98	11.12	12.24
4	3.93	5.04	5.76	6.29	6.71	7.06	7.35	7.6	7.83	8.03	8.21	8.37	8.52	8.67	8.8	8.92	9.03	9.14	9.24
5	3.64	4.6	5.22	5.67	6.03	6.33	6.58	6.8	6.99	7.17	7.32	7.47	7.6	7.72	7.83	7.93	8.03	8.12	8.21
6	3.46	4.34	4.9	5.31	5.63	5.89	6.12	6.32	6.49	6.65	6.79	6.92	7.04	7.14	7.24	7.34	7.43	7.51	7.59
7	3.34	4.16	4.68	5.06	5.35	5.59	5.8	5.99	6.15	6.29	6.42	6.54	6.65	6.75	6.84	6.93	7.01	7.08	7.16
8	3.26	4.04	4.53	4.89	5.17	5.4	5.6	5.77	5.92	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.8	6.87
9	3.2	3.95	4.42	4.76	5.02	5.24	5.43	5.6	5.74	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.65
10	3.15	3.88	4.33	4.66	4.91	5.12	5.3	5.46	5.6	5.72	5.83	5.93	6.03	6.12	6.2	6.27	6.34	6.41	6.47
11	3.11	3.82	4.26	5.58	4.82	5.03	5.2	5.35	5.49	5.61	5.71	5.81	5.9	5.98	6.06	6.14	6.2	6.27	6.33
12	3.08	3.77	4.2	4.51	4.75	4.95	5.12	5.27	5.4	5.51	5.61	5.71	5.8	5.88	5.95	6.02	6.09	6.15	6.21
13	3.06	3.73	4.15	4.46	4.69	4.88	5.05	5.19	5.32	5.43	5.53	5.63	5.71	5.79	5.86	5.93	6	6.06	6.11
14	3.03	3.7	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36	5.46	5.56	5.64	5.72	5.79	5.86	5.92	5.98	6.03
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.2	5.31	5.4	5.49	5.57	5.65	5.72	5.79	5.85	5.91	5.96
16	3	3.65	4.05	4.34	4.56	4.74	4.9	5.03	5.15	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.9
17	2.98	3.62	4.02	4.31	4.52	4.7	4.86	4.99	5.11	5.21	5.31	5.39	5.47	5.55	5.61	5.68	5.74	5.79	5.84
18	2.97	3.61	4	4.28	4.49	4.67	4.83	4.96	5.07	5.17	5.27	5.35	5.43	5.5	5.57	5.63	5.69	5.74	5.79
19	2.96	3.59	3.98	4.26	4.47	4.64	4.79	4.92	5.04	5.14	5.23	5.32	5.39	5.46	5.53	5.59	5.65	5.7	5.75
20	2.95	3.58	3.96	4.24	4.45	4.62	4.77	4.9	5.01	5.11	5.2	5.28	5.36	5.43	5.5	5.56	5.61	5.66	5.71
30	2.89	3.48	3.84	4.11	4.3	4.46	4.6	4.72	4.83	4.92	5	5.08	5.15	5.21	5.27	5.33	5.38	3.43	5.48
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.74	4.82	4.9	4.98	5.05	5.11	5.17	5.22	5.27	5.32	5.36
120	2.8	3.6	3.69	3.92	4.1	4.24	4.36	4.47	4.56	4.64	4.71	4.78	4.84	4.9	4.95	5	5.04	5.09	5.13
infinite	2.77	3.32	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55	4.62	4.68	4.74	4.8	4.84	4.89	4.93	4.97	5.01

- ANOVA and the Tukey Kramer Method can be performed quickly with a given data set using PHStat, which is a Microsoft Excel Add In.
- This analysis has been performed to determine if there are any significant differences in the waste composition between the 12 communities.
- Table 3 shows the data used for the dry combustible portion of the waste stream. Every sample that was collected in the study is included in the analysis.

Table 3: Dry Combustible Portion of the Waste Stream for Each Sample Collected

Swift Current	Humboldt	Wynyard	Esterhazy	Prince Albert	Meadow Lake	Big River	Moose Jaw	Davidson	North Battleford	Melfort	Shellbrook
42%	30%	24%	11%	41%	17%	22%	22%	23%	44%	31%	50%
36%	41%	40%	25%	41%	22%	56%	26%	24%	26%	37%	16%
42%	35%	40%	15%	29%	32%	32%	39%	27%	22%	44%	23%
44%	44%	37%	30%	48%	58%	38%	45%	30%	34%	49%	19%
40%	40%	42%	35%	55%	24%	50%	53%	34%	32%	32%	43%
39%	47%	42%	41%	73%	35%	36%	25%	22%	33%	31%	49%
53%	38%	42%	13%	31%	39%	23%	33%	34%	13%	33%	22%
37%	25%	41%				19%					21%
17%	27%	13%				15%					46%
25%	7%	24%									38%
15%	10%	29%									26%
37%	22%	28%									33%
44%	40%	23%									32%
12%	45%	59%									
26%	42%	49%									
28%	7%	64%									
14%	45%	7%									
33%	22%	32%									
15%	23%	27%									
30%	18%	29%									
18%	32%	34%									
36%	52%	54%									
30%	41%	64%									
37%	25%	25%									
15%	55%										
39%	36%										
31%	32%										
37%	17%										
27%	16%										
36%	22%										
38%	35%										
22%											

- This data is then inputted into the Tukey Kramer Method in PHStat, and ANOVA and Tukey Kramer are performed.
- The level of significance used by PHStat is 0.05.

- PHStat calculates the numerator degrees of freedom (the number of groups) and denominator degrees of freedom (total number of samples minus the numerator degrees of freedom), and the MSW (mean squares within variances).
- PHStat cannot complete the analysis until the user inputs the appropriate Q Statistic.
- Table 4 shows the results of ANOVA for the dry combustible portion.

Table 4: Results of ANOVA for the Dry Combustible Portion

Groups	*Count*	*Sum*	*Average*	*Variance*
Swift Current	32	9.953519	0.311047	0.011077
Humboldt	31	9.743955	0.314321	0.016558
Wynyard	24	8.687921	0.361997	0.021492
Esterhazy	7	1.699261	0.242752	0.014124
Prince Albert	7	3.178911	0.45413	0.022647
Meadow Lake	7	2.276439	0.325206	0.018264
Big River	9	2.915312	0.323924	0.019808
Moose Jaw	7	2.4461	0.349443	0.01294
Davidson	7	1.936902	0.2767	0.002731
North Battleford	7	2.038986	0.291284	0.009196
Melfort	7	2.57757	0.368224	0.004906
Shellbrook	13	4.168989	0.320691	0.014421

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.248016	11	0.022547	1.513625	0.132272	1.854768
Within Groups	2.174812	146	0.014896			
Total	2.422828	157				

- The results of the Tukey Kramer Method for the dry combustible fraction are shown in Table 5. The Q statistic was computed as follows:
  - Denominator degrees of freedom: 166
  - K: number of groups –: 12
  - From Table 2, (using infinite degrees of freedom since the table does not go up to 166), Q = 4.62.

Table 5: Results of Tukey Kramer for the Dry Combustible Portion

Group	Sample Mean	Sample Size
1	0.311047	32
2	0.314321	31
3	0.361997	24
4	0.242752	7
5	0.45413	7
6	0.325206	7
7	0.323924	9
8	0.349443	7
9	0.2767	7
10	0.291284	7
11	0.368224	7
12	0.320691	13

Other Data	
Level of significance	0.05
Numerator d.f.	12
Denominator d.f.	146
MSW	0.014896
Q Statistic	4.62

Comparison	Absolute Difference	Std. Error of Difference	Critical Range	Results
Group 1 to Group 2	0.003274	0.02174873	0.1005	**Means are not different**
Group 1 to Group 3	0.050949	0.02330413	0.1077	**Means are not different**
Group 1 to Group 4	0.068296	0.03601038	0.1664	**Means are not different**
Group 1 to Group 5	0.143083	0.03601038	0.1664	**Means are not different**
Group 1 to Group 6	0.014158	0.03601038	0.1664	**Means are not different**
Group 1 to Group 7	0.012876	0.0325623	0.1504	**Means are not different**
Group 1 to Group 8	0.038395	0.03601038	0.1664	**Means are not different**
Group 1 to Group 9	0.034347	0.03601038	0.1664	**Means are not different**
Group 1 to Group 10	0.019764	0.03601038	0.1664	**Means are not different**
Group 1 to Group 11	0.057177	0.03601038	0.1664	**Means are not different**
Group 1 to Group 12	0.009644	0.02838435	0.1311	**Means are not different**
Group 2 to Group 3	0.047676	0.02346466	0.1084	**Means are not different**
Group 2 to Group 4	0.07157	0.03611448	0.1668	**Means are not different**
Group 2 to Group 5	0.139809	0.03611448	0.1668	**Means are not different**
Group 2 to Group 6	0.010884	0.03611448	0.1668	**Means are not different**
Group 2 to Group 7	0.009602	0.03267739	0.151	**Means are not different**
Group 2 to Group 8	0.035122	0.03611448	0.1668	**Means are not different**
Group 2 to Group 9	0.037621	0.03611448	0.1668	**Means are not different**
Group 2 to Group 10	0.023037	0.03611448	0.1668	**Means are not different**
Group 2 to Group 11	0.053903	0.03611448	0.1668	**Means are not different**
Group 2 to Group 12	0.00637	0.0285163	0.1317	**Means are not different**
Group 3 to Group 4	0.119245	0.03707197	0.1713	**Means are not different**
Group 3 to Group 5	0.092133	0.03707197	0.1713	**Means are not different**
Group 3 to Group 6	0.036791	0.03707197	0.1713	**Means are not different**
Group 3 to Group 7	0.038073	0.03373258	0.1558	**Means are not different**
Group 3 to Group 8	0.012554	0.03707197	0.1713	**Means are not different**
Group 3 to Group 9	0.085296	0.03707197	0.1713	**Means are not different**
Group 3 to Group 10	0.070713	0.03707197	0.1713	**Means are not different**
Group 3 to Group 11	0.006228	0.03707197	0.1713	**Means are not different**
Group 3 to Group 12	0.041305	0.0297196	0.1373	**Means are not different**
Group 4 to Group 5	0.211379	0.04613021	0.2131	**Means are not different**
Group 4 to Group 6	0.082454	0.04613021	0.2131	**Means are not different**
Group 4 to Group 7	0.081172	0.04349197	0.2009	**Means are not different**
Group 4 to Group 8	0.106691	0.04613021	0.2131	**Means are not different**
Group 4 to Group 9	0.033949	0.04613021	0.2131	**Means are not different**
Group 4 to Group 10	0.048532	0.04613021	0.2131	**Means are not different**
Group 4 to Group 11	0.125473	0.04613021	0.2131	**Means are not different**
Group 4 to Group 12	0.07794	0.04045887	0.1869	**Means are not different**
Group 5 to Group 6	0.128925	0.04613021	0.2131	**Means are not different**
Group 5 to Group 7	0.130207	0.04349197	0.2009	**Means are not different**
Group 5 to Group 8	0.104687	0.04613021	0.2131	**Means are not different**
Group 5 to Group 9	0.17743	0.04613021	0.2131	**Means are not different**
Group 5 to Group 10	0.162846	0.04613021	0.2131	**Means are not different**
Group 5 to Group 11	0.085906	0.04613021	0.2131	**Means are not different**
Group 5 to Group 12	0.133439	0.04045887	0.1869	**Means are not different**
Group 6 to Group 7	0.001282	0.04349197	0.2009	**Means are not different**
Group 6 to Group 8	0.024237	0.04613021	0.2131	**Means are not different**
Group 6 to Group 9	0.048505	0.04613021	0.2131	**Means are not different**
Group 6 to Group 10	0.033922	0.04613021	0.2131	**Means are not different**
Group 6 to Group 11	0.043019	0.04613021	0.2131	**Means are not different**
Group 6 to Group 12	0.004514	0.04045887	0.1869	**Means are not different**
Group 7 to Group 8	0.025519	0.04349197	0.2009	**Means are not different**
Group 7 to Group 9	0.047223	0.04349197	0.2009	**Means are not different**
Group 7 to Group 10	0.03264	0.04349197	0.2009	**Means are not different**
Group 7 to Group 11	0.044301	0.04349197	0.2009	**Means are not different**
Group 7 to Group 12	0.003232	0.03742293	0.1729	**Means are not different**
Group 8 to Group 9	0.072743	0.04613021	0.2131	**Means are not different**
Group 8 to Group 10	0.058159	0.04613021	0.2131	**Means are not different**
Group 8 to Group 11	0.018781	0.04613021	0.2131	**Means are not different**
Group 8 to Group 12	0.028751	0.04045887	0.1869	**Means are not different**
Group 9 to Group 10	0.014583	0.04613021	0.2131	**Means are not different**
Group 9 to Group 11	0.091524	0.04613021	0.2131	**Means are not different**
Group 9 to Group 12	0.043991	0.04045887	0.1869	**Means are not different**
Group 10 to Group 11	0.076941	0.04613021	0.2131	**Means are not different**
Group 10 to Group 12	0.029408	0.04045887	0.1869	**Means are not different**
Group 11 to Group 12	0.047533	0.04045887	0.1869	**Means are not different**

- Table 5 shows that for the dry combustible portion of the waste stream, there is no significant difference between any of the communities.
- This same method was utilized for the other three fraction of the waste stream. Significant differences were found between the following:
  - Swift Current and Prince Albert- Putrescible Fraction
  - Prince Albert and North Battleford- Putrescible Fraction
  - Two out of 264 comparisons made were found to be significantly different. This is approximately only 0.76%.
- What might cause significant differences?
  - As the Q statistic gets lower, the chances of finding significant differences between groups gets higher.
  - Having more groups (communities) with fewer samples in each group would also increase the likelihood of having significant differences between groups.
- When data from the city of Saskatoon waste composition study is added in as a thirteenth group, are there any significant differences?
  - Yes, the following are found to be significantly different:
  - Meadow Lake and Saskatoon- Plastic Fraction
  - Swift Current and Prince Albert- Putrescible Fraction
  - Prince Albert and North Battleford- Putrescible Fraction
  - Three out of 312 comparisons made were found to be different. This is approximately only 0.96%.

Appendix D

Statistical Analysis Results (Digital Format)